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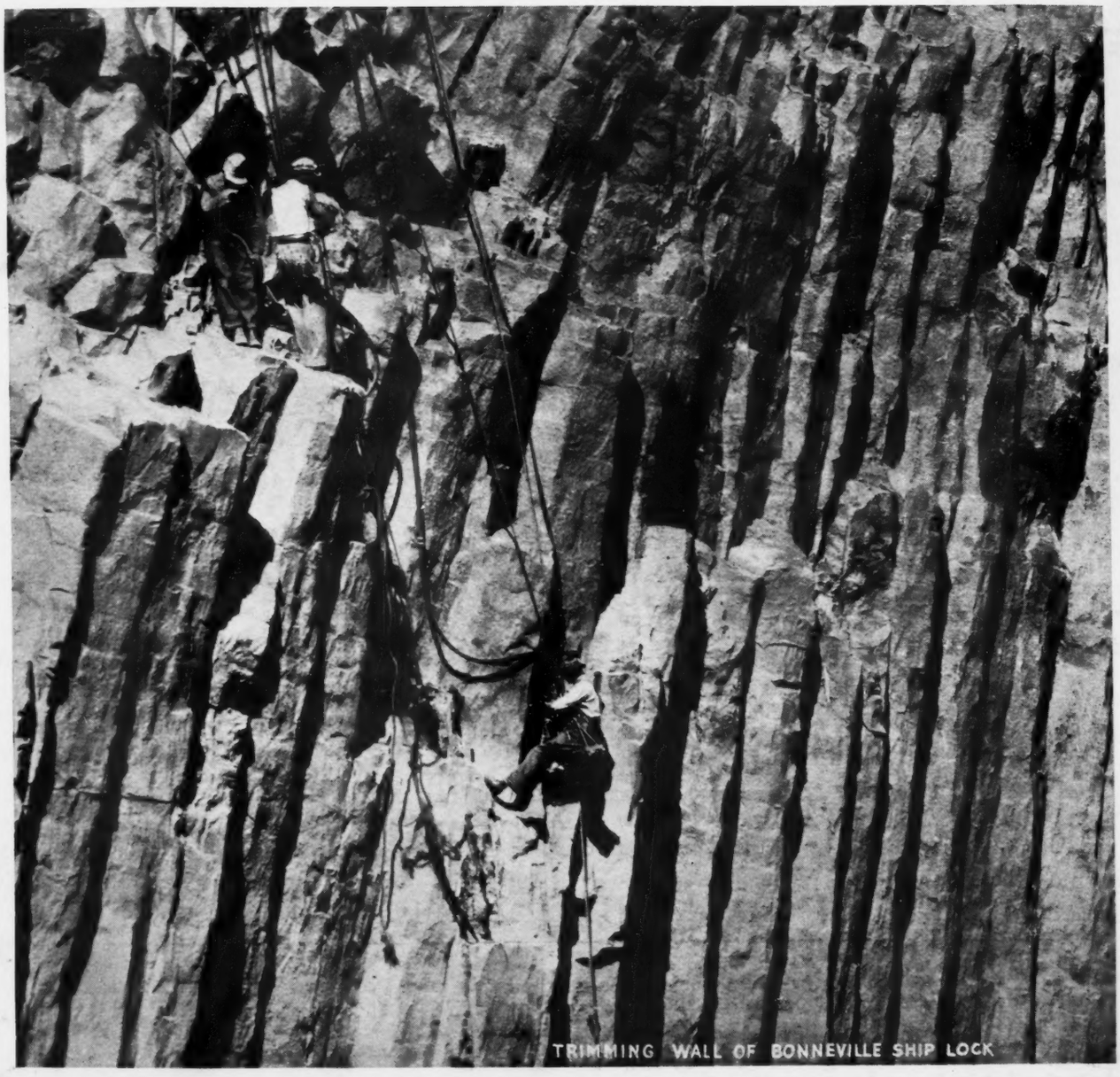

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OCTOBER, 1935

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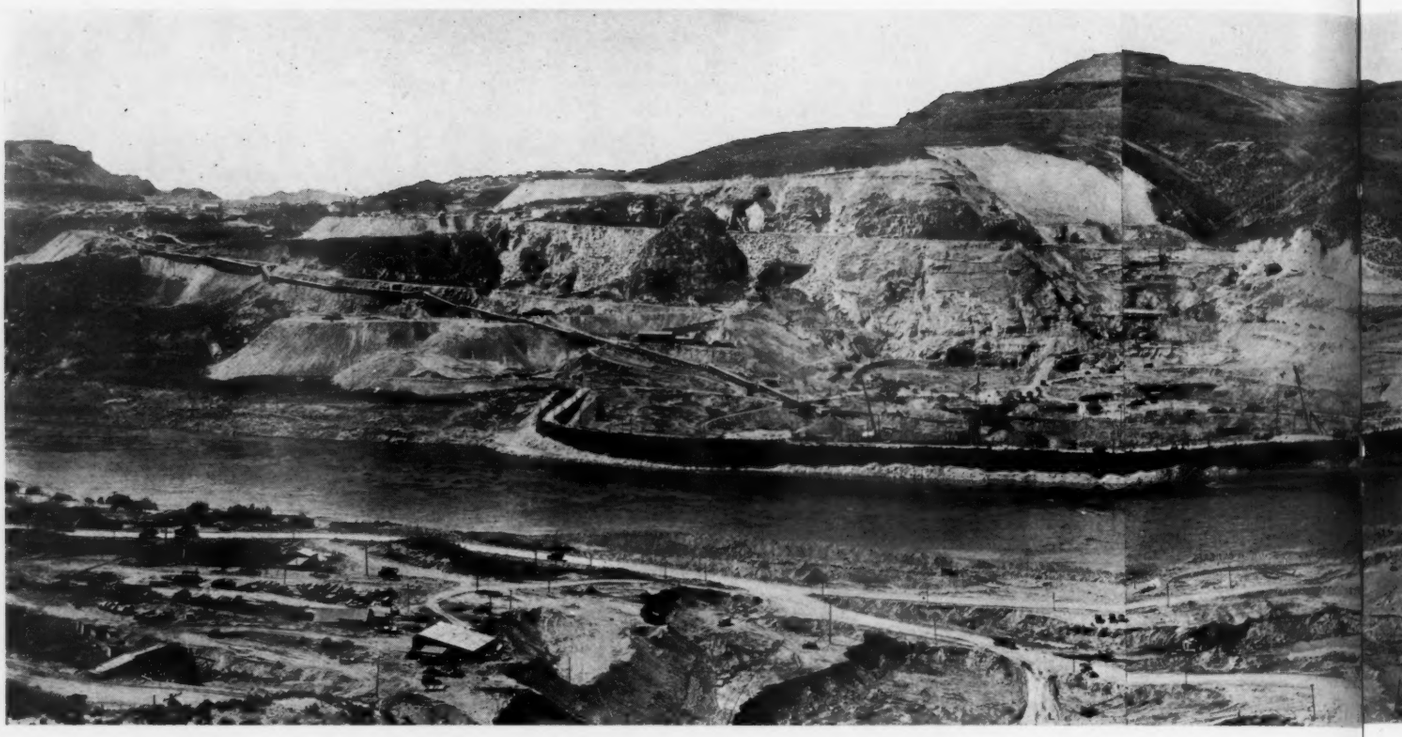


PANORAMA OF ACTIVITIES AT THE DAM SITE

The construction area, as photographed from the east bank of the Columbia River. The stream flows northward, or toward the right. In the left half of the picture is the west cofferdam, the largest of its type ever built. Excavating is substantially completed, the spoil being moved to a disposal area in Rattlesnake Canyon by the conveyor system which slopes upward toward the left. On the near side of the Columbia, directly below the cofferdam, stripping is underway and preparations are being made to construct the east cofferdam. In the foreground on the opposite page are the contractor's shops. Above them, across the river, is the Government camp, locally known as Engineers' Town. Mason City, the contractor's camp, is beyond the right-hand edge of the picture.

GRAND COULEE DAM

General Features of the Ultimate Power and Irrigation Scheme and Scope of the Current Contract

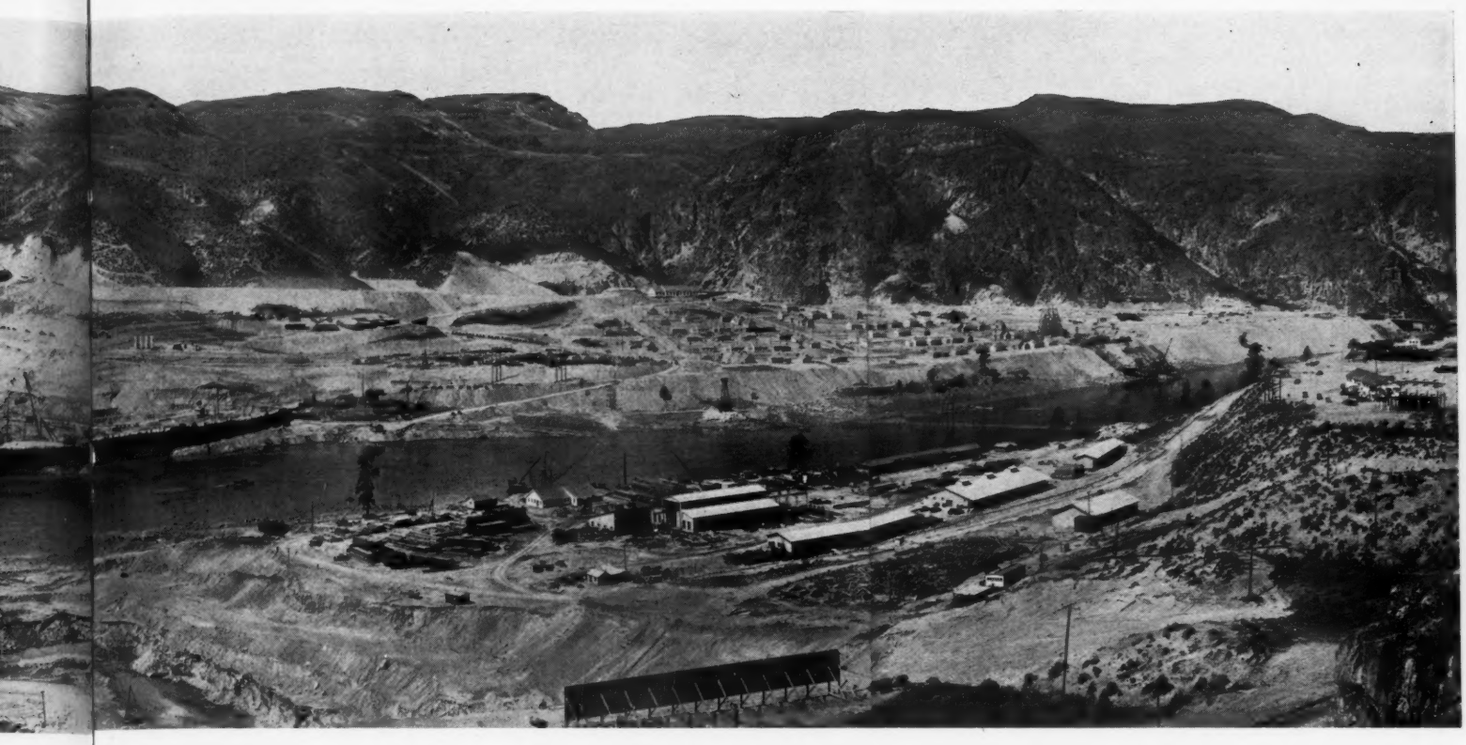
Harold O'Connell

GRAND Coulee Dam is today becoming a reality with a speed and sureness that stands in marked contrast to the slow, step-by-step planning and long study that have kept this project alive for more than 30 years. Contrast is indeed the keynote of the entire scheme—the contrast of the deep Columbia River Canyon with the rolling plain country through which it passes—the almost tragic contrast of tremendous quantities of water rushing past acres of arid land. The land is fertile, even ideal for irrigation purposes. There is a generous proportion of sand, which is necessary to prevent "caking" of irrigated soil, together with a productivity reputed to be two and a half times the average for all cultivated lands in the United States. One Wenatchee dry-land farmer, lured to the region by abnormal rainfall a generation ago, summed up the irony of the situation by saying: "That river is always a good place for a fellow to drown himself when he goes broke."

More than irrigating water will some day bless this section of the country. Power will be available in almost staggering quantities, and at a cost that should prove tremendously attractive and induce industries new and old to consider the region as a location. A comprehensive discussion of the units involved in this huge power and irrigation scheme will be given later; but an outline sketch of the main elements of the project, and particularly of the change in plan which alters the entire aspect of the work being done at this time, is a necessary introduction.

Aside from the favorable foundation and topographic conditions at the Grand Coulee dam site, the controlling factor in locating the dam has been the existence of the Grand Coulee itself. This channel, caused by the glacial diversion of the Columbia River, is 50 miles long, up to five miles wide, and as deep as 900 feet. It constitutes a perfect connection through high ground to the Big Bend country, which lies in the southeastern part of the State of Washington, east of the Columbia River, south of Quincy, Ephrata and Soap Lake, and north of the Snake River.

A million acres, often referred to as "the finest body of arid land awaiting reclamation in the West," will be directly irrigable when the Grand Coulee project is completed. The dam itself will raise the water 350 feet, and will be instrumental in furnishing power for pumping that water from the reservoir so created to an irrigation basin in the Grand Coulee. The pumping station, the dikes to form the reservoir within the coulee, and the connecting canals and distributaries are of a magnitude that put this whole undertaking in a premier place among the world's reclamation works. In addition, low-head pumping units, using power obtained at different points along the canal where there are sudden drops in elevation, will be the means of lifting a portion of the water an added 100 feet for reclaiming some 200,000



acres more in that region. The general locations of the gravity- and of the low-head-pumping areas irrigable are shown on an accompanying map.

While the sponsors of the Grand Coulee development have always had in mind the entire project and its ultimate far-reaching blessings, the fact that the cost of the dam and irrigating system, complete, would total approximately $400,000,000 has, in the past, proved a barrier when attempts were made to secure a state or a national appropriation to cover the whole work. Because Grand Coulee Dam has been repeatedly called to the attention of various administrations, and also because it was much in the limelight during the creation and organization, in 1933, of the Public Works Administration, the project was one of the first to be approved by that body. PWA, at the insistence of President Roosevelt, authorized an initial expenditure of $63,000,000 on the dam. The U. S. Bureau of Reclamation was then faced with the problem of immediately putting men to work on the undertaking, the engineering plans for which were far from finished.

Since core drilling had furnished a reasonably accurate clue to the logical axis of the dam, it was decided to enter at once upon a short-term contract for 1,000,000 cubic yards of excavating on each side of the river. David H. Ryan of San Diego, Calif., was the successful bidder. Favored by the warmest recorded winter in the history of the section, Ryan forged ahead of schedule and was awarded an additional 500,000 cubic yards—all to be removed within the original period of 150 days set.

During this time plans were being made for the utilization of the $63,000,000 ap-

DOWN TO ROCK BOTTOM

Extensive core drilling disclosed a firm granite foundation at the dam site underneath surficial clay and silt. When uncovered, the rock surface proved to be more irregular than drilling had indicated. The pictures show east-abutment rock (above) and a strip along the bottom of the canyon.

propriation. That amount, falling far short of the total needed for the work, and short even of that required for the completion of a dam that could eventually be used to supply irrigating water, was to be spent on development of the power alone. Excavating was to be done on the basis of the ultimate project; and it was then that the terms "low dam" and "high dam" came into being. The low dam was to contain about 3,500,000 cubic yards of concrete and was to become the upstream heel of the future high dam. The downstream toe, which was subsequently to be incorporated in the high dam, was also to be built and was to serve as a cofferdam when carrying that structure to its full height. There was nothing new in 2-stage construction, as it had been used with satisfactory results in the case of other dams of comparable design—notably among them being the Assuan Dam on the Nile, which has been raised twice, and the Sweetwater Dam near San Diego, Calif.

Bids were called for, and the Mason-Walsh-Atkinson-Kier Company was awarded the construction contract on the low bid of $29,339,301.50. That company is an affiliate of the Silas Mason Company, Inc., New York, N. Y., of the Walsh Construction Company, Davenport, Iowa, and of the Atkinson-Kier Company of California, with Silas B. Mason, chairman of the board, Thomas J. Walsh, president, and H. L. Myer, manager. Francis Donaldson is chief engineer, and M. Harvey Slocum is general superintendent. The activities of this and of other concerns in the building of the Grand Coulee Dam are described elsewhere in this issue.

Notwithstanding assurances from nu-

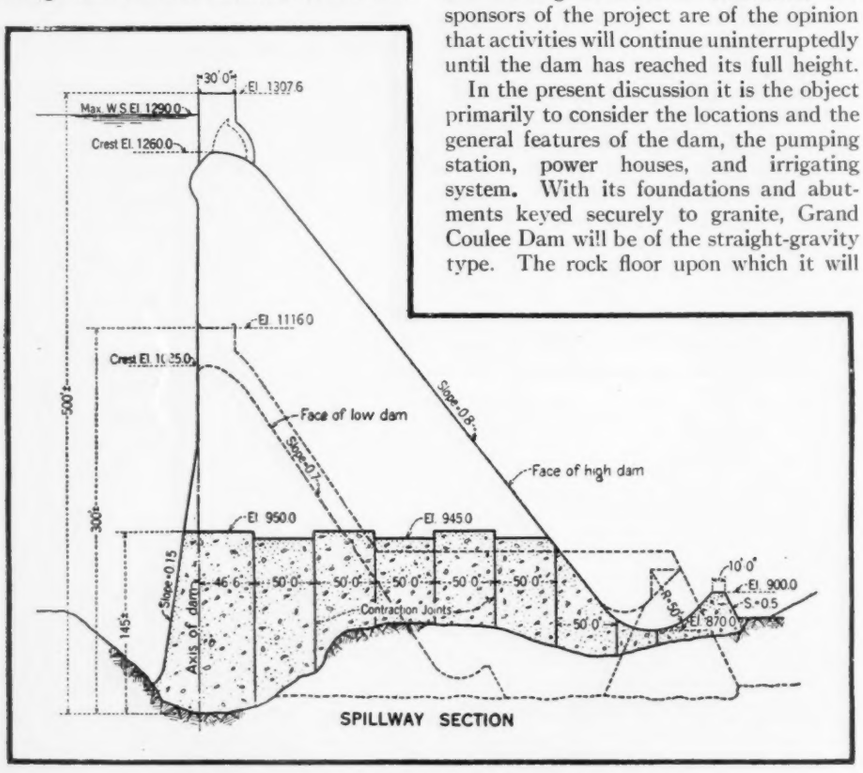
merous sources of the feasibility of 2-stage construction at Grand Coulee, provisions were made in the contract for a change in plan, giving the Government the option to take over the contractor's plant at a stipulated sum in the event of such a change. The Government, however, did not choose to exercise that right; and when the order was issued on July 5, 1935, to proceed on the basis of the high dam, an alternative agreement with the contractor was reached. Now, instead of pouring 3,500,000 cubic yards of concrete in the construction of the low dam, a corresponding amount will be placed to form the base for the high dam; and inasmuch as excavating, from the start, was done with the high dam in view, and as concrete placement was, if anything, simplified, a new contract was not deemed necessary.

Briefly, the major changes include: Placement of concrete; longitudinal contraction joints spaced 50 feet apart in the concrete; arrangement for metal tubing for artificial cooling; permanent downstream cofferdam to be absorbed by the base of the high dam; power-house construction, excepting necessary foundations, will be eliminated; power penstocks will be partly eliminated; the tailrace for the east-side power house will be excavated; and some additional excavating for the foundations will be made. Actual work on the 500-foot or high dam was thus initiated. While there is no official assurance that a new contract for its completion will be forthcoming when the existing contract is concluded, the sponsors of the project are of the opinion that activities will continue uninterruptedly until the dam has reached its full height.

WITHIN THE GRAND COULEE

One of the flanking basaltic walls of the gorge which the ancient Columbia River cut while temporarily diverted from its true course by a mammoth ice dam. The cliff is 900 feet high and is composed of more than a dozen separate lava flows.

In the present discussion it is the object primarily to consider the locations and the general features of the dam, the pumping station, power houses, and irrigating system. With its foundations and abutments keyed securely to granite, Grand Coulee Dam will be of the straight-gravity type. The rock floor upon which it will rise is rugged in topography, varying from 2,800 to 3,000 feet in width. Several distinct but rather narrow depressions exist; and core drilling indicates that one of these extends to a depth of more than 100 feet below the general level. On the east side the rock has a slope of approximately 1½:1 and on the west side of ¼:1. Overlying the granite foundation are layers of silt and clay varying in thickness from 20 to 150 feet. The removal and disposal of this overburden is one of the principal items in the construction program.



HOW THE DAM PLAN WAS CHANGED

The original scheme at Grand Coulee called for the building of a 300-foot-high dam for power generation only, together with a permanent cofferdam at the downstream toe to facilitate subsequent heightening of the dam to 500 feet. This design is shown by the dotted lines. On June 7 last the plan was changed: the "low dam" was eliminated and provision was made for the use of the concrete called for under the current contract in building the base for the ultimate "high dam." The shaded area shows this modified design. The solid lines outline the high dam.

What is now known of the foundation conditions at the dam site is based on collective core-drilling data obtained during investigations made by the State of Washington in 1921, by the U. S. Army Engineers in 1928, and by the U. S. Bureau of Reclamation, which started exploratory drilling in 1933 and has continued to date. A total of 164 holes has been put down for this purpose, some of the angular ones being 850 feet long. The deepest of these holes reached 657 feet below the bottom of the Columbia's channel.

Grout will be forced into the foundation under the heel of the dam both before and after the placing of concrete. Low-pressure grouting will be carried to a depth of approximately 20 feet in a strip about 60 feet wide before concreting, while high-pressure grouting will be forced to a depth of 100 feet after the mass concrete is in position. But before the grouting operations are taken in hand it is planned to examine the site by drilling holes from 50 to 60 feet deep at 200-foot intervals along the axis of the dam with a 3-foot "Calyx" core drill. Into these holes geologists will be lowered, enabling them to study the rock

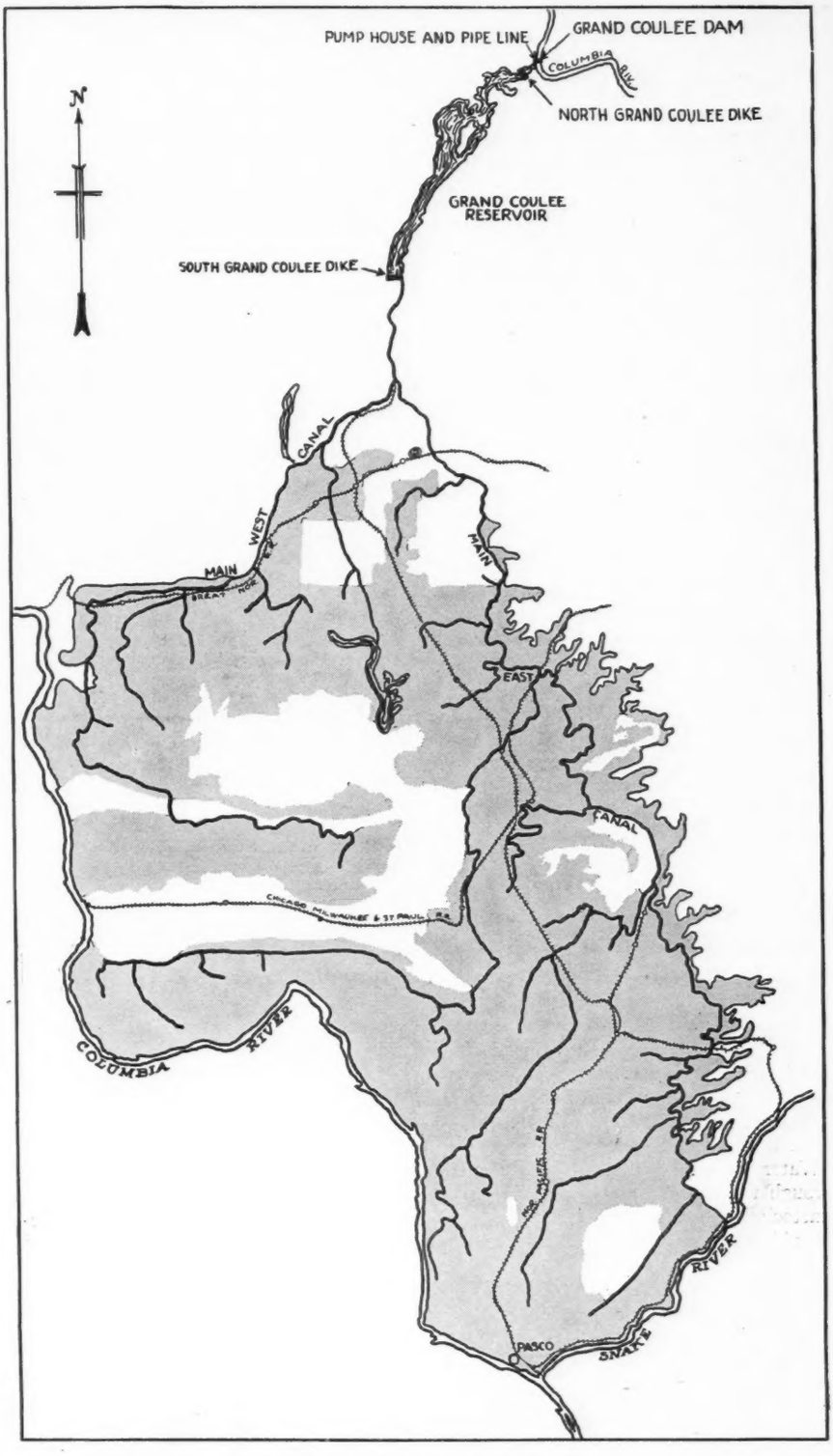
at first hand and thus to determine the existing conditions in a manner not otherwise possible. So far two such holes have been drilled.

The dam itself will be of massive concrete, and will be provided with keyed contraction joints placed at 50-foot intervals each way. The poured concrete is to be cooled artificially, and this is to be accomplished by pumping chilled water through coils of 1-inch pipe extending through the concrete on 5- and 5½-foot centers.

Of the total crest length of 4,300 feet, 1,650 feet in the center will be left for a spillway. Control of the water will be effected by eleven drum gates, 135 feet long and 28 feet in diameter, which are designed to roll down into corresponding notches in the spillway crest. When in their up position, they will form an effectual barrier and will help to create a lake extending to the Canadian border 151 miles upstream and having a total reservoir capacity of 7,300,000 acre-feet, or a usable storage of around 6,180,000 acre-feet. With the gates down, the spillway will have a maximum discharge capacity of 1,000,000 second-feet. Surmounting the dam and crossing the spillway on a 11-span bridge will be a 26-foot roadway. It should be mentioned here that the matter of dissipating the energy of discharge water as it rushes down over the downstream face of a dam is a serious problem and is being investigated with unusually large models, built to scale, at the hydraulic laboratories at Fort Collins and Montrose, Colo. Experimental curves for the bucket at the toe of the dam are being tested to check theoretically developed designs.

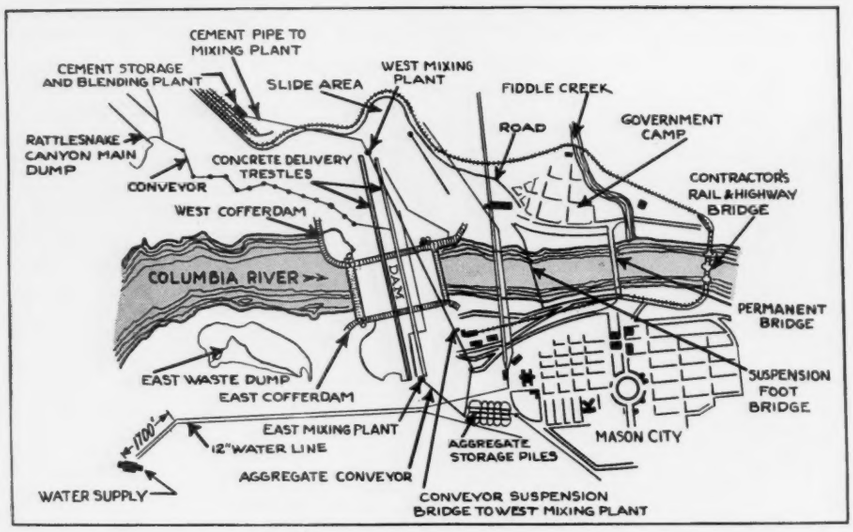
The plans call for outlet works with a combined discharge capacity of 150,000 second-feet under full head. They will be in the form of ten pairs of 8½-foot conduits controlled by ring-follower and paradox gates installed in tandem in the upstream face of each conduit. Ten semicircular trash-rack structures of reinforced concrete protect these works, which are to be used only in case of plant repairs—including pumping units—and when the flow of water exceeds the capacity of the plant. Otherwise any lowering of the surface of the reservoir from the highest attainable level on down as much as 80 feet—which, according to present plans, is permissible during periods of low water—is to be effected by passing the water through the power houses. thus producing electricity.

Two power houses are planned, one at each end of the downstream toe of the dam. These concrete-and-steel structures will be 78 feet wide and more than 600 feet long and will be made watertight to a point several feet above the maximum flood-water elevation. The generator floors will be just above the maximum recorded tail-water elevation. In each power house will be nine main generating units each of which will be driven by a hydraulic turbine rated at 147,000 hp. when operating under a



THE IRRIGATION SCHEME

Ultimately, about 1,200,000 acres of fertile but now arid land will be brought under irrigation by virtue of Grand Coulee Dam and its appurtenant structures. The general elevation of this land is from 630 to 730 feet above the present surface of the Columbia River. The dam will raise the river level 350 feet, and water will then be pumped the remaining 280 feet to a storage basin which will be formed by damming the adjacent Grand Coulee at two points. By means of the canal system shown, this water will be distributed to the irrigation district. It will reach 1,900,000 acres by gravity flow. The additional 200,000 acres can be served by pumping the water to elevations not to exceed 100 feet by means of power generated at points of considerable fall in the main canal system. Certain areas which are nonirrigable are shown in white within the shaded area. It is expected that more than a half-century will elapse before all the land is under cultivation.



GENERAL LAYOUT OF OPERATIONS

The dam-site area, showing the various structures and facilities that have been provided for the conduct of the work. In addition to the rail, highway, and foot bridges, and the conveyor suspension bridge, a separate pile trestle has been installed between the cofferdam areas. Over this the spoil from the east excavation is conveyed to a connection that transfers it to the main belt conveyor extending to Rattlesnake Canyon.

330-foot head. Each generator is rated at 105,000 kw. at 120 rpm., 22,000 volts, 60 cycles. The transformers, one bank for each generator, will be located immediately behind the power plants and will step up the generator voltage to 220,000.

All low-voltage switching and auxiliary equipment is to be located in the substructures of the power houses, and two plant-service generating units of 6,000 kw. each will be installed in the station on the west side of the river. In each building will be two cranes of sufficient capacity to lift the heaviest part of any of the generating machinery. Provision will be made for adequate dismantling space, and there will be a machine shop to handle the necessary repair work.

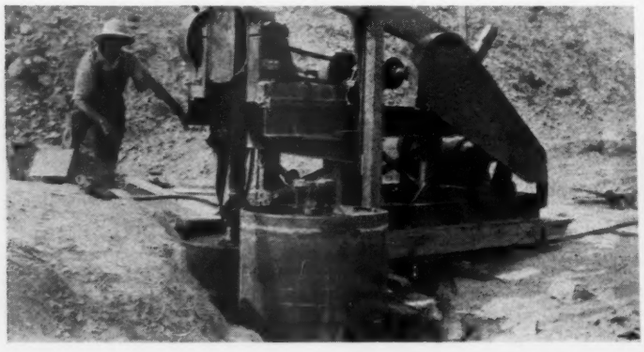
Water for each turbine will be carried through the dam by means of an 18-foot penstock built of heavy steel plate and embedded in the concrete. These are to pass through the dam at elevation 1,180, whence they will follow the downstream face of the dam to their respective turbines in the power houses. Each penstock is to be controlled by a butterfly gate.

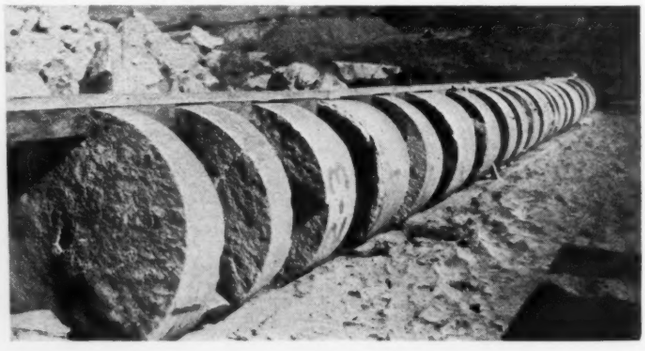
Situated on the reservoir shore just upstream from the west abutment of the dam will be one of the largest pumping plants ever constructed. It will be a reinforced-concrete structure about 640 feet long and 100 feet wide, and most of it will be below water when the reservoir is at maximum height. A gantry crane mounted on top of it will travel its full length and have access to the machinery through removable hatches over each pumping unit. Drainage of the interior of the structure to the tail-race below the power houses will be by means of an outlet tunnel, which will also carry the power cables from the west plant to the pumping plant. The twenty single-stage pumps, each having a capacity of 800 second-feet under a maximum head of 370 feet, will be driven by synchronous motors rated at 33,000 hp. at 200 rpm. The generators and the pumps for which they supply energy are to be so coördinated as to permit varying the frequency of the current to give the most efficient pumping speed for operating heads ranging from 280 to 360 feet, exclusive of friction.

The 8½-foot discharge opening of each pump will be connected to a separate steel pipe leading to a common outlet structure at the head of the Grand Coulee Canal. At this point a siphon arrangement with an automatic air valve will prevent the backflow of water from the canal when any pump is taken out of service. From the outlet works a 1½-mile canal will deliver the discharge from the pumping plant to the irrigation reservoir in the Grand Coulee. The plan is to utilize only off-peak and secondary power in pumping into this basin, which will be 23 miles long and have an area of 21,000 acres. It will have a maximum capacity of 1,050,000 acre-feet of water, or a useful capacity of 339,000 acre-feet. Earth-fill dikes faced with concrete on the reservoir side will form this basin. The north dike will be 92 feet high and the south dike will rise 97 feet above the original ground level. Extending southward from the latter the concrete-lined main canal will flow for a distance of approximately ten miles before branching off and continuing as the main west canal and the main east canal.

An accompanying map shows the principal features of the system necessary for the irrigation of the lands lying within the compass of the entire project. It is of such magnitude that, unless a radical change is made in the present schedule of operations, it will take the better part of at least two decades to carry it to completion.

Dr. Elwood Mead, Commissioner of the U. S. Bureau of Reclamation, and R. F. Walter, chief engineer, are in charge of the Grand Coulee project. F. A. Banks is resident engineer, with headquarters at the Government camp, and he is assisted by James H Miner, office engineer, and Allan F. Darland, field engineer.





PROBING THE FOUNDATION

To obtain data on the character of the underlying rock, a series of 36-inch-diameter holes is being drilled to depths of 50-60 feet along the axis of the dam. These openings are being made by means of a "Calyx" core drill. Geologists will be lowered into the holes to examine the rock at close range. The cores extracted from such a hole (right) also form a permanent record of the nature of the formation. The "Calyx" drill rig is illustrated in operation (left), a spare bit being shown in the foreground.

DAM SITE AND NEIGHBORING TOWNS

An aerial view of the construction area. On the left bank is Mason City, built by the contractor. Across the river from it is Engineers' Town, the Government settlement. Beyond the latter is the west cofferdam within which excavating for the dam footings is about completed. The ultimate dam, only the base of which is now contracted for, will be 4,300 feet long at the crest and will rise more than 500 feet from the lowest foundation. It will contain more than three times as much concrete as went into Boulder Dam.

Housing Grand Coulee Workers

COINCIDENT with the inauguration of any isolated construction project such as the Grand Coulee is the task of providing adequate housing facilities for laborers and supervisors. As no sizable community was available for occupancy by the 3,500 men that were to be employed directly in the building of Grand Coulee Dam, plans were made for the creation of two major camps, one on each side of the Columbia downstream from the dam site.

On the west bank of the river is the Government camp, locally called Engineers' Town. There, on a fan-shaped plot are the administration building, residences, dormitories, stores, etc.—permanent structures that have been erected by the Government and that will remain even after the construction men have left the area. The colonial type of architecture prevails; and fairly extensive landscaping is now underway—some 150 varieties of shrubs and trees being set out, making of the camp a garden spot in striking contrast to the surrounding sage-covered hillsides and plains.

Engineers' Town is built on ground sloping down to the river bank. Its streets are laid out radially and converge toward the administration building, which stands at the highest point. Within this area are 65 frame-and-concrete residences which are thoroughly modern in respect to water supply, plumbing, and heating, and have built-in garages. There are also two men's dormitories each of 48 rooms arranged to accommodate one or two persons. These are being supplemented by four dormitories having 48 single rooms—temporary structures that have been put up north of and just beyond the limits of the town site. In this same section are 24 court-type houses,

TYPICAL STRUCTURES IN ENGINEERS' TOWN

As the Government settlement will remain after the construction period, it has been planned accordingly. Buildings are attractive and well constructed, extensive landscaping is in progress, and some 150 varieties of trees and shrubs are being set out. At the left, above, is the grade school which, in addition to classroom facilities, contains a modern gymnasium. There are 65 residences, made up of three types, depending upon the number of persons they are to accommodate. One of each type is shown on this page.

also temporary, for the families of workers not permanently employed by the Government, as well as a modern grade school.

The business and shopping district lies in the southern corner of the camp. Here are to be found a garage, fire station, bus terminal, and shops, with the Government warehouse immediately adjoining. The latter is about 380 feet in length, and is connected by rail with the Government construction spur extending to Odair.

Power is delivered by the Washington Water Power Company over the contractor's transmission line from Coulee City; and two complete water-supply systems are in service. One furnishes nonpotable water from the Columbia for utility purposes, and the other spring water for drinking and domestic consumption. The river water is handled by an automatic pumping plant the inlet pipes of which are built into the west pier of the now completed highway bridge between Engineers' Town and Mason City, the contractor's camp. Sewage disposal is effected by means of a thoroughly modern plant having its discharge outlet at a point downstream from the community. Excellent natural drainage exists, and no pumping of sewage is necessary. With its macadam streets, attractive buildings, and spacious parks, the place is substantial and pleasing in appearance—is, in fact, a model town that will before many years have elapsed house the operating force of one of the world's greatest power-generating installations.

Facing the Government camp is Mason City, on the east bank of the Columbia. It is a much larger community, but less pretentious because it is intended for only temporary use. Despite that, and the speed with which it was created, it is surprisingly orderly, well built, and conveniently laid out.

Its dwellings come under three classifications—A, B, and C, depending upon the size and cost of construction. Class A houses are 1-room cottages with a small bath and kitchenette. Sixty-four of these are grouped in the southeastern part of the town adjacent to 60 cabin-type dormitories accommodating 1,360 men. The main residential section is in the northern half of Mason City. Here are 128 two-room or Class B homes, and 87 three-room Class C homes, all of which have ample closet space and commodious kitchens and baths. Each group of four is served by a 4-car garage centrally placed with respect to the dwellings. A separate dormitory has been provided for the 35 women employed in the administration offices and in the contractor's various establishments. All houses in Mason City are occupied—there is even a waiting list, and the 64 one-room cottages are especially popular with the many newlywed couples that have come to the project.

By the terms of the contract, all the living quarters built in the camp were restricted as to type and designed to meet ordinary requirements. Nevertheless, the comfort and convenience of the occupants have not been overlooked, testifying to an employee consideration that characterizes the entire community. The maintenance of lawns and gardens is optional with the tenants; and in this respect it is interesting to state that well-nigh all the houses in the main residential district were surrounded with grass, flowers, and even shrubbery and trees during the first summer of the town's existence.

Between the two sections just described is the commercial and recreation center which boasts a bank, a post office, a large department store, restaurants, a big garage, a theater, a 40-room hotel, and numerous shops. Twilight league baseball is popular, and a full-sized diamond does a flourishing business, while a 4-unit concrete tennis court is well patronized.

The school system includes a high school and a grade school in which the first, second, and third grades are taught. For the succeeding five grades the children of Mason City attend a Government maintained school in Engineers' Town. Conversely, the younger children and those of high-school age in the Government camp go to the Mason City schools. Government buses carrying all of them to and fro. Churches are two in number, one Catholic and the other Protestant in denomination; and for the medical care of the inhabitants

WHERE THE CONTRACTOR'S EMPLOYEES LIVE

Although it will be razed when the dam and associated structures are finished, Mason City, the contractor's town, has been built without neglecting beauty and comfort. It is the nation's first all-electric community, and no smoke is to be seen there. The pictures above show a residential street, and one of the 60 cabin-type dormitories which provide accommodations for 1,360 men. Three types of dwellings (below) are available for family occupancy. These vary in size, but all have kitchens and bathing facilities. The maintenance of lawns and gardens is optional with tenants, but local pride has resulted in well-ordered grounds around virtually every structure. The houses, prefabricated in Spokane, were shipped in sections. The monthly rental for a home is 2 per cent of its cost.

the contractor has provided a modern 40-bed hospital staffed by four doctors and twelve nurses. It is equipped with the latest X-ray and other apparatus.

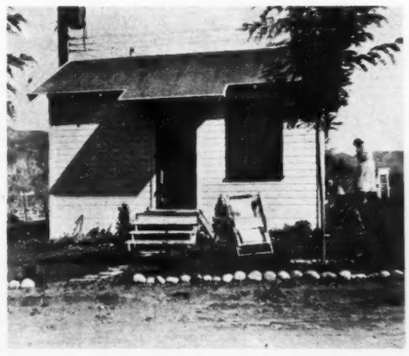
The majority of the workers take their meals in the large mess hall that has its own bakery and refrigerating system. It is capable of seating 1,360 men at one time, and a charge of $1.20 per employee per day is made. It might be mentioned here that workers living in detached dwellings pay a rental that is fixed by contract at 2 per cent of the cost of the house per month, while those quartered in the dormitories pay twenty-five cents per person per day.

In addition to the main administration building, the contractor maintains a construction office, one camp office, a large warehouse connected by rail with the Government's line to Odair, a machine shop, and numerous repair shops. The latter is close to the cofferdam area of the east-bank abutment.

Mason City has been heralded as the world's first all-electric town, and much interest has been aroused by the use of electricity for heating throughout. Because the cost of satisfactory oil or coal furnaces would have been high as compared with the small portable electric units in service there, and also because of the very low rate at which the contractor obtains his power, electric heat at Grand Coulee is not a luxury.

Adequate fire protection and an ample supply of water are assured by a pumping plant located one mile above the dam on the Columbia. Three 500-gpm., centrifugal pumps—two driven electrically and one by a gasoline engine—deliver water from this plant through a 12-inch wood-stave line to three wood-stave settling basins having a total capacity of 350,000 gallons. Semi-automatic chlorination at the pumping station purifies the water for drinking purposes. The sewage-disposal system is designed for a town of 3,000 people. It consists of a wooden Imhoff tank and discharges into the river about a mile below the town site.

Plans for the contractor's camp were approved on September 29, 1934, and by January 1, 1935—after three months of uninterrupted activity and change—Mason City was virtually completed and occupied. This remarkable record was to no small extent made possible by the prefabrication of the houses in Spokane, Wash., 90 miles distant. Walls, partitions, etc., in sections ready for erection, were delivered at the building site.



The Government may acquire the houses and facilities of Mason City when the present contractor finishes his work by exercising its optional right as written into the contract. For $25,000 may be obtained all buildings and installed utilities—sewer, water, and electrical connections. Similar arrangements have been made by contract for the purchase of two additional items of the contractor's plant: the 30-mile transmission line to Coulee City may be purchased by the Government at a price of $25,000, and all installed construction equipment for $100,000.

Business is brisk, and people are busy in the Grand Coulee area. Northeast of it is an aviation field used by the contractor, salesmen, and even visitors to the project. As is generally the case where huge undertakings of this kind are in progress in isolated regions, numerous boom or mushroom towns have sprung up in the outskirts of the camp. Their names, to the embarrassment of postal authorities, have much in common. There is a Grand Coulee and a Coulee Center, as well as Coulee Heights, Coulee Dam City, Basin City, Electric City, Osborne, and Rim Rock, and all are thriving places comprising a few houses and many stores, amusement halls, and other attractions that offer a little glamour and much contrast to the well-patrolled communities that are the nucleus of the Grand Coulee project.

THE HAMMER PILOT

The job of the man in the boatswain's chair is no sinecure. Hanging in midair, in fair weather and foul, he threads the steel piles for stringing and spots the steam hammer for driving them. Two piles are driven at a time. Note the fishtail guide on the hammer.

Construction Methods at Grand Coulee Dam

ON SEPTEMBER 25, 1934, the Mason-Walsh-Atkinson-Kier Company was given formal notice to proceed, as general contractor, with the building of the first unit of the Grand Coulee Dam. One year has elapsed since that date—a year of preparation and of amazing activity that will eventually result in harnessing the swift-flowing Columbia for the production of useful power and for the delivery of some of its own water to arid, irrigable lands.

Rivers and streams must always be reckoned with during dam construction. Builders invariably "play safe," and yet there is always the possibility of a combination of devastating circumstances that may put teeth in the flow of the mildest stream and impose tremendous penalties on construction projects along its course. Rivers in the Northwest are subject to wide seasonal variations in flow because of potential floods in the form of snow and ice that can be counted upon to pour down from the mountains at their headwaters at periodical intervals when wind or sun or warm rains melt them. When such a run-off is augmented by an abnormal rainfall over a large section of the watershed, the resultant torrent rushing through a narrow gorge can easily make any attempt on man's part to control the flow seem puny.

The Columbia, mightiest of all the Northwest streams, has none of the temperament of the Colorado, whose flash floods may descend without warning. The Columbia's periods of rampage are closely predictable, and its behavior can in nowise be called erratic. Nevertheless, its great size, depth, and swift and strong flow engender construction difficulties of the first rank, especially in the case of a large-scale undertaking like the Grand Coulee. Because of these facts, and particularly because of the great variation between high and low water, it is not surprising that bridges across the Columbia are few in number and that "fair-weather" ferries are many. Not until last year was an attempt made to span the river with a pile-trestle below the Canadian boundary. In view of all this it is truly astonishing that the first concrete for the dam is to be poured this month.

Excavating on both sides of the stream kept pace with the initial activity of getting the camp in readiness. As the foundation was to be carried many feet below the river level, cofferdams were necessary at an early stage. An earth dike was therefore left on the east bank along the riverward edge of the excavation. But as this dike was not expected to protect the area during the high-water period, the equipment below flood-water elevation was removed in March of this year, and thereafter excavating proceeded at the higher elevations.

During the fall of 1934 work was mainly centered on the excavation for the west abutment. While plans were being made for the belt conveyor system—which was to be built by the Jeffery Manufacturing Company at its Columbus, Ohio, plant—trucks were used to transfer the material to spoil areas at several points on a hillside upstream from the dam site. These areas had a limited capacity, and were as much as 500 feet above the river level.

The decision to run a belt conveyor system from the west-bank excavation to a discharge point at the rim of Rattlesnake Canyon—more than a mile away and approximately 400 feet above the surface of the stream—was reached because of several factors. In the first place, because of cliffs, there was not available within a radius of several miles on that side of the river a low-level spoil area adequate for the 10,000,000 cubic yards of excavated material (total contract yardage). Secondly, a railway or truck road to such a dump would have been costly to construct and

to operate. Rattlesnake Canyon's capacity to receive spoil, and its proximity to the dam site—at least by contrast with other possible spoil areas—were in its favor, provided an economical method of transport could be devised.

The Silas Mason Company and the Walsh Construction Company, members of the affiliate that has the present contract, had had previous experience with belt conveyors in connection with the East Boston Vehicular Tunnel and the diversion tunnels of the Fort Peck Dam. At Boston, muck was thus handled within the tunnel only, while at Fort Peck, because of the curve of the tunnels, the use of belt conveyors had to be confined to the disposal of material delivered by cars to a feeder at the tunnel portals. The satisfactory performances of these two systems led to the adoption of a belt conveyor at Grand Coulee.

The system was designed at the dam site, and is what might be called custom built. Speed was an important factor; and numerous activities in progress at the time of its installation had to be taken into consideration in placing its several units. Mobility both in the excavation and on the dump was, of course, essential if operating economy was to be obtained; and the conveyor had to be far sturdier in construction than if it had been intended for industrial purposes. Adequate safety features also had to be provided for the protection of the unskilled workers that would come in contact with it. Shovel-progress and truck-traffic studies dictated the starting points for the system, which is so arranged that it can accommodate itself both to the lowering of the pit and to the extension of the spoil area as the fill in the canyon is brought to grade.

Accompanying drawings show the locations and the functions of the conveyor system, consisting of four dump feeders, of four tributary belt conveyors, of a main belt, and of a stacker. Each of the tributary belts is 350 feet long, and the main belt is made up of nineteen sections varying in length—the shortest being 156 feet with a 14° slope and the longest 415 feet. At present the latter is 5,600 feet long, but it will be extended somewhat as the spoil bank reaches farther into Rattlesnake Canyon. With an aggregate feeder-conveyor length of 1,400 feet, the system now totals 7,000 feet, but ultimately will be about 1½ miles in extent. The main conveyor moves at a speed of 620 feet a minute, and was designed to carry 2,500 cubic yards per hour, or 52,500 cubic yards per 21-hour day. To date, the maximum day's work has been 50,700 cubic yards.

Beginning at the excavation, the tributaries are loaded by the feeders, which are of the apron-conveyor type. The chains of the latter have an ultimate strength of 200 tons and are equipped with cast-steel rollers of large diameter. Two of these feeders operating at capacity could keep the main conveyor fully loaded; but as truck-haul distances vary as the work progresses, a third unit is used to insure a steady flow of material. One of the four is generally being repaired or relocated.

Tractor-pulled wagons and dump trucks (ranging in capacity from 12 to 24 cubic yards) deliver their loads to a grillage of heavy built-up bars spaced for 13-inch openings. A bulldozer follows each wagon or truck over the grizzly, crushing large pieces of shale through the openings with its tracks, pushing aside bowlders, and cleaning up the area for succeeding loads. If not rejected, the bowlders would doubtless damage the belts, for many of the grizzly bars are badly battered. A small power shovel dumps the bowlders into trucks for removal.

Each feeder mechanism is mounted in a large steel frame that is protected by wood sheathing when the unit is relocated below ground level; and there is ample working space within a feeder for making repairs and for cleaning out any dirt that may sift in through the apron or between the sheathing. The whole assembly weighs approximately 65 tons. The chief function of the feeders, aside from loading the tributary belts, is to equalize irregularities in truck deliveries and to assure as uniform a flow as possible. This is accomplished by a 40-cubic-yard skirt and hopper above the conveyor apron.

To facilitate moving, the feeder assembly is planked on the underside and fitted with steel shoe plates. In shifting to a lower level, a trench is dug and the unit maneuvered into position by three tractors: one

MECHANICAL DIRT EATER

Like a great serpent, the belt conveyor system sprawls across the landscape, disgorging earth and rock from the cofferdam excavations into Rattlesnake Canyon, more than a mile away. Its series of endless belts move at the rate of 620 feet per minute and will handle a cubic yard of material every 1½ seconds. One of the feeders to the main conveyor appears in the foreground.

pulling, one snubbing, and the third acting as a bulldozer for sluing. It is then buried; the ground leveled off for truck access; and the belt and control connections made. Each set-up of a feeder is good for several weeks of operation.

Loading of the main belt at the focal point or hub of the tributaries is controlled manually from a station at that point. The operator there can stop any one of the tributary belts; but he cannot start them unless the main belt is running. It is his function to maintain a steady discharge, and while he has no control over a prolonged shortage, a surge hopper placed there affords some storage that he can draw upon and also serves as a protection against momentary overloads. In transferring from one section of the main belt to another, the material drops 4 or 6 feet, the larger fall being at angle points in the line where more headroom is required. Delivery on to the receiving belt is direct, there is no intervening retarding chute. However, a "rail splitter" was employed for a time when rock from the cofferdam area was being handled. Oversized, rubber-covered idlers are used for a distance of about 8 feet under the shock area of each section, the brackets for these being cushioned with rubber in a manner similar to the frame mounting of automobile engines. The customary 3-pulley idlers are spaced 42 inches apart under the loaded belt: under the return belt they are on 7-foot centers.

The main conveyor belt is 60 inches wide, about ¾ inch thick and is made of rubber-covered 8-ply, 32-ounce duck. In the case of the telescoping units at the discharge end, to be described later, the fabric is 42-ounce duck. Very little wear results from conveying earth and soft material, but large rocks and broken stone sometimes tear the fabric. When repairs are needed, the belt tension—induced by the counterweighted gravity take-ups—is released, and new belting is laced in to replace the damaged section.

The control stations and the driving mechanisms are at the forward end of each conveyor section. The motors, of 200 hp. each, are protected by casings and are equipped with reduction gears and V-belt drive. Motor controls are interlocked, and stopping one section also stops all preceding sections, while those succeeding continue to carry their loads to the canyon. Likewise, in starting at the head of the system, where the master control station is situated, the preceding belts can be put in operation only when the succeeding ones have come up to normal speed. To put any section in motion it is necessary only to push the control button for that section; but it takes about ten minutes to start the entire system. All units are connected by telephone with the master control station, and the several individual stations or head houses are linked by a walkway paralleling the belt. The whole conveyor is roofed for the protection of men and machinery, and to prevent wetting and freezing of the material in transit. One man is normally required for each four or five head houses. Banks of step-down transformers supply power to each group of three conveyors. The entire line is well lighted: all moving parts are guarded as much as possible; and safety instructions are conspicuously posted.

The "crowning glory" of the system is the stacker, without which its smooth and continuous operation would not be economically possible. The main-line conveyor was ready for the transportation of material from the pit area on December 13, 1934, after three months spent in designing, manufacturing, and assembling it for work. The first dumping was done directly over the canyon rim, giving more time in which to complete the stacker, which was put in service as soon as it was erected.

An extensible conveyor, to which 50-foot belt sections can be added as needed, is the first unit in the stacker system. The head of this unit, for a length of about 50 feet, straddles a 4-wheel, truck-mounted section, enabling it to advance 50 feet. This telescoping member delivers the spoil on to the pivot end of the stacker boom, at which point the boom and the feeder section are moved ahead by a 10-hp. tractor unit. The boom is 175 feet long, and is supported by a tractor that swings it through an arc of 180°. Above this tractor is the master station from which the chief operator controls the entire conveyor system.

As the fill progresses, the tractor units move forward or radially at the rate of 10 feet per minute. Their crawler mountings are flexible, so that uneven ground in the spoil area, or failure of the boom tractor to swing in a true arc, will not set up twisting or binding stresses in the conveyor sections. The pressure exerted on the soil by these mobile supports does not exceed 6 or 7 pounds per square inch, thus avoiding difficulty that otherwise would be encountered on the new dump because of yielding material.

It is not necessary to stop delivering to the stacker until the 50-foot forward movement of the telescoping unit has been effected. Then another section is added to the extensible conveyor, a procedure that usually requires about 40 minutes. This is generally done during one of the 1-hour rest periods at the end of each 7-hour shift; and it takes a crew of trained men to change the set-up in such a short time. Thus far, the record operating period without shutdown from any cause has been 59 hours, 8 minutes. Shutdowns usually occur when a large bowlder manages to get through a grizzly and over a feeder, resulting in delays that may vary from a few seconds to a minute, depending upon the point along the line at which it is first noticed. On an average, less than 6 per cent of the total working time is lost from all causes of this sort. However, if any belt is seriously damaged by a large rock, the conveyor system has to be stopped immediately for repairs of longer duration.

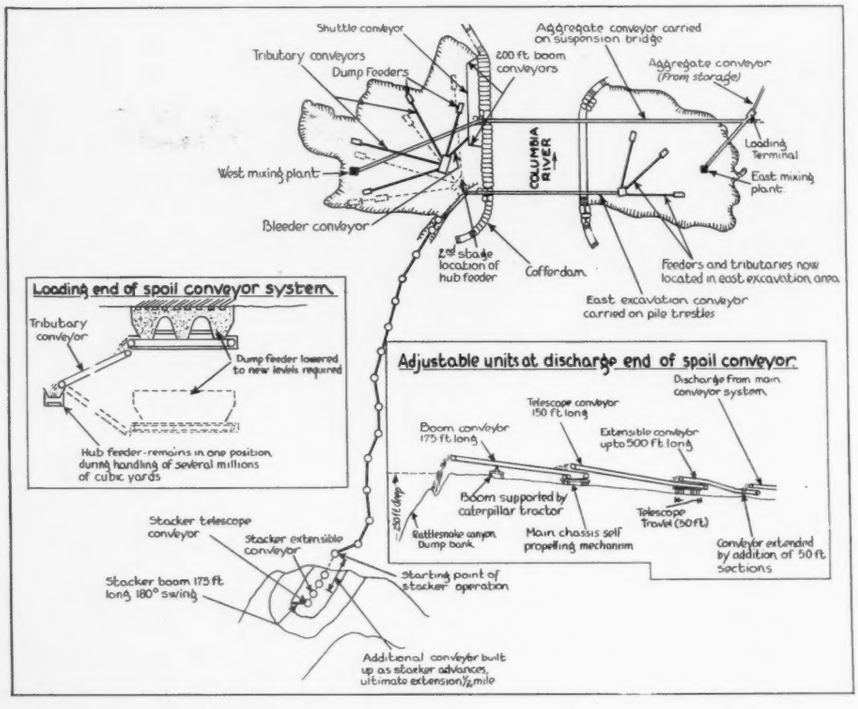

Shuttle conveyor
Aggregate conveyor carried on suspension bridge
Tributary conveyors
Dump Feeders
200 ft. boom conveyors
Aggregate conveyor (From storage)
COLUMBIA RIVER
Loading Terminal
West mixing plant
East mixing plant
Bleeder conveyor
2nd stage location of hub feeder
Cofferdam
Feeders and tributaries now located in east excavation area
East excavation conveyor carried on pile trestles
Loading end of spoil conveyor system
Tributary conveyor
Pump feeder lowered to new levels required
Hub feeder-remains in one position during handling of several millions of cubic yards
Adjustable units at discharge end of spoil conveyor
Discharge from main conveyor system
Telescope conveyor 150 ft. long
Boom conveyor 175 ft. long
Extensible conveyor upto 500 ft. long
Boom supported by caterpillar tractor
Rattlesnake canyon Dump bank
Main chassis self propelling mechanism
Telescope Trowel (50 ft.)
Conveyor extended by addition of 50 ft. sections
Stacker telescope conveyor
Stacker extensible conveyor
Stacker boom 175 ft. long, 180° swing
Starting point of stacker operation
Additional conveyor built up as stacker advances, ultimate extension ½ mile

DIAGRAM OF SPOIL CONVEYOR SYSTEM

As now extended, the conveyor system for muck removal is serving cofferdams on both sides of the river. The crossing of the stream is made on a pile trestle. The sections of the main conveyor, which are of varying lengths, are marked by small circles. The ultimate length of the entire system will exceed 1½ miles.

Something quite unforeseen in the handling of spoil has been the action of the material at the forward edge of the dump. The angle of repose is about 45° for a short time, then the mass slowly but continually slides forward, assuming a slope of about 5 to 1. This "pancaked" base is now more than 1,000 feet ahead of the expected edge of the dump, and advancing at the rate of approximately 5 feet daily. The dump itself is nearly 250 feet deep under the discharge of the stacker, which moves upward as well as forward; and a general spoil-area-surface slope of 7½° is being maintained.

At this writing the work on the west-side excavation is substantially completed. Original, tentative plans called for the relocation on the east side of the present conveyor system. But as the existing set-up has proved so satisfactory, and as Rattlesnake Canyon can accommodate the required yardage of spoil, it was decided to bridge the Columbia with a pile-trestle on which to support a connecting main-line conveyor. This system has been in operation since September 12, and three feeder units have been installed on the east bank.

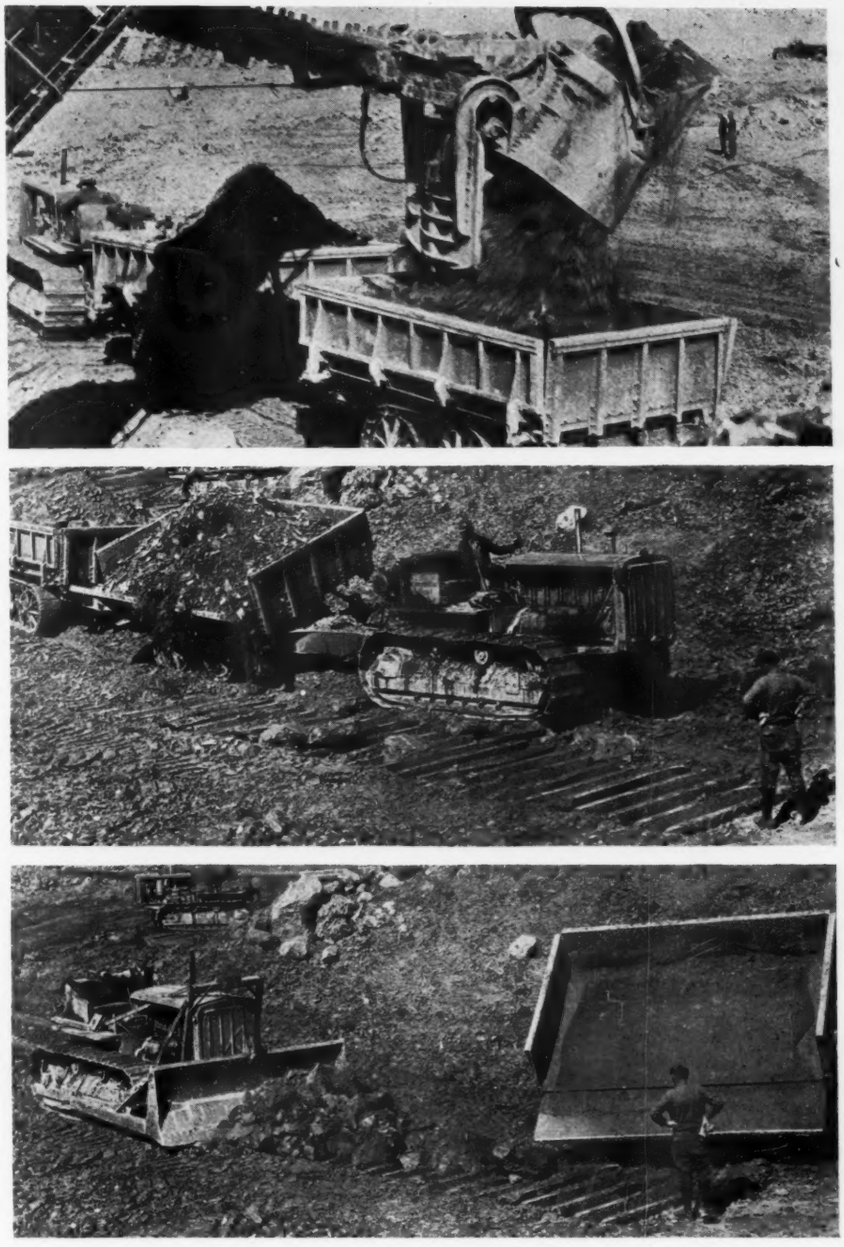
From the time the building of the Grand Coulee Dam was seriously contemplated, there was considerable speculation as to how Item No. 1 of the bid sheet, "Diversion and care of the river . . ." was to be accomplished. It was recognized that the "diversion and care" of the Columbia was a man-sized job—in fact, it has been referred to as one of the most important diversion jobs ever undertaken; and in submitting his bid the contractor assumed all risks and was placed "on his own" so far as engineering plans and their execution were concerned.

It was decided that the cofferdams necessary for this work be constructed in three stages; and reference to the accompanying diagrams will show their general arrangement and structural features. The west-side cofferdam, the first to be taken in hand, is completed; the east cofferdam is now being built; and the cross-channel cofferdam will not be started until after high water next year. That cut-off will serve to divert the river over the west concrete base during the rearing of the spillway section in mid-channel. The east cofferdam is comparatively small, and is a low, rock-filled crib faced with steel sheet piling.

The finished cofferdam is 3,000 feet long, and encloses about half of the excavation area, although the amount of excavating there is more than 50 per cent of the total. It is built chiefly of steel sheet piling, of which 13,000 tons, having an aggregate length of 667,000 feet, was used. This first unit was scheduled as a six or seven months' job; but it was finished in 90 days, and that despite the fact that it had to be carried out against great odds during a northwestern winter—a highly praiseworthy accomplishment. Had there been any delays in getting this barrier in place before the spring and summer high water there might have been danger of seriously encroaching upon the 1,650 days allowed under the contract for the entire project. Yet the only preliminary work that could be done before the formal notice to proceed came through on September 25, 1934, was the sinking of test pits to bedrock and the making of wash borings to determine what length of steel sheet piling would be needed. Actual pile driving was not begun until New Year's Day.

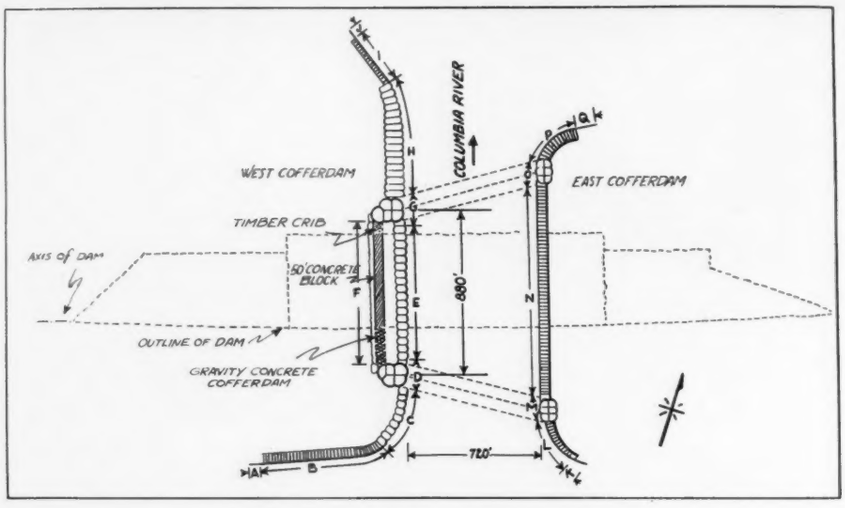
Four different types of construction distinguish the west cofferdam, as accompanying diagrams show. The end sections, B and I, consist of a row of interlocking steel sheet piling facing the river and of a paralleling wall of 4-inch rough sheeting and heavy timbers set 37 feet back, all braced with special tie-rods. The piling was driven to the refusal point, which was established at 80 strokes of a 3½-ton hammer for 1-inch penetration. The tops were cut off uniformly at elevation 990. Low-water elevation is 940.

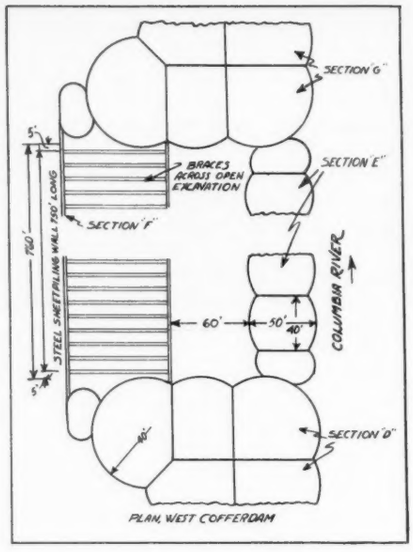
The intervening sections are generally cellular in construction and built for the most part of steel sheet piling. Section H is cellular below elevation 965, and from



LOADING SPOIL FOR DISPOSAL

Tractor-drawn wagons are loaded by a 5-cubic-yard electric shovel (top) and hauled to the nearest tributary conveyor terminal. Loads are side dumped upon a grillage of steel bars above a conveyor feeder (center). A bulldozer follows the wagons, crushing large pieces of shale through the openings and pushing aside bowlders (bottom).





GENERAL LAYOUT OF COFFERDAMS

The west cofferdam is finished, the east one is under construction, and the central cofferdam will be placed later—the dotted lines showing locations for its end walls. The more detailed drawing of the west cofferdam (right) shows where the first concrete will be poured between the two parallel lines of sheet piling. The letters refer to the various cellular sections which are described in the accompanying text.

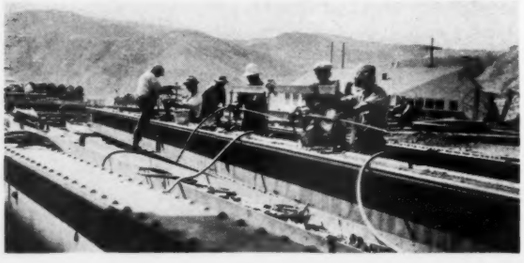
there on up to elevation 990 the arc construction is maintained on the river side but supplanted on the inner side by a timber wall with tie-rod bracing. The cells are about 90x36 feet in dimensions and have a 36-foot-radius arc. Section H was given this extra width so that it would be stable in itself. Sections C and E are substantially the same as H, except that 50x40-foot cells with a 40-foot-radius arc were placed below elevation 965.

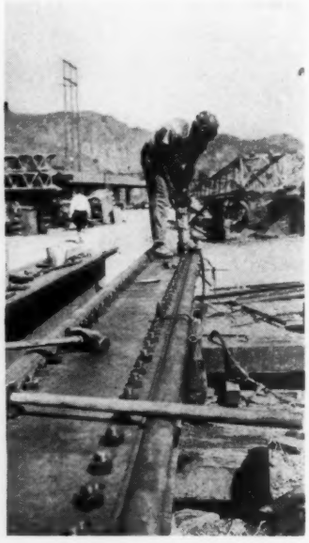
Cell clusters D and G have 40-foot-radius arcs and are built of steel sheet piling with steel-sheet-piling diaphragms up to elevation 965 and tie-rod diaphragms up to elevation 990. These cells will constitute the connecting points in the cross-river closure. Because they extend westward into the cofferdam area they will permit the placing shortly between sections E and F of the first 50-foot block of concrete for the dam. Section F consists of a single line of piling driven to bedrock 150 feet west of the inner face of Section E and links cell clusters D and G.

Before pile-driving for the west cofferdam could be started, it was necessary to clear the site of its overburden of bowlders and basalt spall by trenching with a clamshell bucket. Numerous bowlders, ranging in size up to 500 cubic yards, were encountered, and these demanded considerable drilling and shooting underwater. In addition, in order to minimize the effects of currents, breakwater cribbing had to be constructed at those points where the cofferdam extended into the water. A trench 12 feet wide at the base was carried into the till where piling was to be driven.

It had been planned to force the piling to bedrock, but this idea was abandoned when the nature of the 60- to 80-foot blanket of glacial drift overlying the bedrock in the channel was discovered. Tightly compacted and impervious, the material—"young shale," as it is locally known—proved highly resistant, and gave considerable trouble throughout the work. On the other hand, it has exceptional sealing qualities, as evidenced during the past season of high water that put the cofferdam to a severe test.

Pile-driving was initially done from a trestle on which traveled whirleys handling the piling and the steam hammers. Each cell was strung and completely interlocked before emplacement—guide frames of both laminated-wood wales and steel I-beams, curved to the proper radius, assisting in the operations. Alternate lengths of 80- and 40-foot piling, weighing 38.8 pounds per foot, were used, their 3/8-inch webs being welded at the junction points after stringing. A man on a boatswain's chair threaded the piling and spotted the steam hammer. An uncomfortable job, this, for aside from the dangers incident to the work, itself, several prolonged cold spells saw the thermometer hover around 18° and 20° below zero Fahrenheit. A fishtail guide devised by the contractor greatly aided in spotting the hammer and in holding it in a vertical position for driving two piles at a time. Some bowlders were encountered and, with the exception of a few large ones that had to be dug out, were generally disposed of by sinking a pipe alongside the blocked pile and blasting a hole, into





FABRICATING BOX PILING

At Grand Coulee, as on all large construction jobs, compressed air performs diversified services. These pictures show pneumatic tools being used to assemble box piling. At the upper left holes are being drilled with Type CSBL drills. At the lower left some of the 24,000 one-inch rivets required are being driven by No. 8A riveting hammers. At the right a box pile is being speedily bolted together with a Pott impact wrench.

which the bowlder could topple, a little below and to one side of it.

Despite the availability of 22 rigs for handling the hammers, pile-driving progress was discouraging at first. Means were sought to step it up, for it was realized that if the work were to continue at that rate there would be little hope of completing it before high water. The answer was a 4-hammer gantry rig straddling Section E. This structure was supported on either side by trestles and moved along as operations advanced. It had a base width of 70 feet, and carried four steam hammers controlled by trolley-mounted electric hoists on movable booms, thus permitting any hammer to be spotted over any part of a cell beneath the gantry. In this way a 50-per-cent increase in driving efficiency was obtained, as well as a substantially lower cost as compared with hammer-placing by long-boom hoisting rigs. The greatest depth of water in which piling was driven was 20 feet.

It should be mentioned here that the presence of bowlders in the river channel had caused the contractor to relocate the cofferdam and to bring the part paralleling the river 150 feet nearer shore, thus eliminating the berm previously contemplated. But when it was found that pile-driving to bedrock was still impractical, it was decided to provide a 60-foot berm.

The sheet piling at F has now been cut off to elevation 935, and an additional sheet-piling cut-off placed lengthwise between sections E and F. The space between the two steel faces is being excavated in 15-foot cuts and braced apart as excavating proceeds. As concrete for the first 50-foot block is poured in this area these braces will be removed and the piling braced against the concrete. This block of the dam is to be tied with circular steel coffer cells to cell cluster D and with a wood-crib structure and circular steel coffer cells to cell cluster G, thus forming the west end of the central or cross-channel cofferdam. When that is finished the river will be diverted and section E removed, thus exposing the eastern face of the block and permitting adjoining blocks to be poured in the central dam area.

Surprisingly little water seeped into the west cofferdam when the Columbia reached its peak at elevation 974 during June. Twenty-one precautionary shored wells, of 4x6 feet, had a combined discharge of only 500 gpm. However, unusually heavy snows had fallen in the higher regions of the watershed during the past winter, and other than the normal discharge from those sources might have caused the river to exceed the 550,000-second-foot stage at which it was estimated the cofferdam would be flooded. Provision has been made for deliberately flooding the area by placing stop-log gates in a 23x20-foot opening in Section I and by installing a concrete sluiceway to guide the water into the area with a minimum of erosive action on the berm behind the cofferdam.

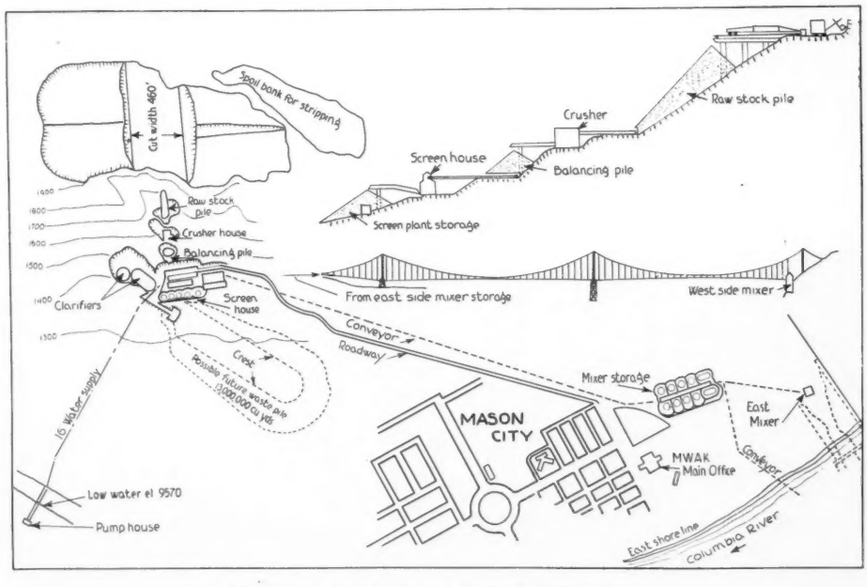
Still another innovation introduced because of the need for haste in building the cofferdam was a shuttle conveyor for filling the cells. Trucks were used to transport the first 275,000 cubic yards of fill; but on March 1 they were supplanted by the shuttle conveyor. It consisted of three units: a 200-foot bleeder conveyor from the hub of the main conveyor system; an 870-foot traveling conveyor; and two 200-foot boom conveyors, one at either end of the traveling conveyor.

Discharge from the bleeder conveyor was directly into a hopper above the belt of the traveling conveyor and about midway of Section E. The latter conveyor had a length of 800 feet, and its 12-foot-gauge track paralleled the cofferdam and extended 800 feet in either direction from the hopper, giving a total run of 1,600 feet. Belt-drive was reversible; and the two boom conveyors permitted placing material in any of the numerous cells. The lower end of each boom conveyor was supported by the tractor and track under the associate end of the traveling conveyor, while the discharge end was supported by a turntable mounting carried on the 28½-foot-gauge track of the whirleys just inside the cofferdam.

A glacial deposit of sand and gravel, known as the Brett Banks, will supply all the concrete aggregate for the dam. Although the deposit is only 1½ miles northeast of the dam site it is more than 900 feet above low water, thus creating a transportation problem similar to that encountered in the case of the west-abutment excavation. Again, belt conveyors are to be used; and from shovel to mixer transfer will be by this system. When it is considered that approximately 3,500,000 cubic yards of concrete will be required under the present contract for the base of the dam, and that the aforementioned pit may eventually have to furnish aggregate for about 8,000,000 more cubic yards, it is obvious why considerable emphasis was placed upon economical transportation.

Aggregates of all the necessary sizes are found in this pit in quantities far in excess of present and future requirements; but preliminary exploration has revealed that fines predominate. This has called for the installation of a plant capable of quarrying, transferring, and separating twice as much material as will be delivered in the form of finished and sorted aggregates, and for a transfer system and waste pile for the disposal, possibly, of 13,000,000 cubic yards of fines. Test pits seem to indicate the presence of two gravel deposits having an interposed layer of fine sand. Aggregate for the present contract is being taken from the upper deposit, which is about 80 feet thick. The lower one is 100 feet thick.

Stripping of a 3-foot layer of overburden was completed during the past summer. The pit material is at present being excavated by but one 5-cubic-yard electric power shovel which delivers its load directly into a hopper at the end of a 200-foot boom conveyor. Bowlders in excess of 16 inches are cast aside by a grizzly above the boom hopper. This boom discharges on to an extensible conveyor which, in turn, transfers the load to the main conveyor and thence to the screening plant. The conveying system will be extended as quarrying progresses; and the boom, being pivoted, follows the shovel around as it



THE GRAVEL CONVEYOR SYSTEM

Concrete aggregates are being produced at a deposit 1½ miles from the dam site and 900 feet above low-water level. In undergoing treatment, as shown in the cross sectional flow sheet at the upper right, they descend more than 500 feet. Classified aggregates will be conveyed from stock piles to storage bins at the east-side mixer by a 48-inch belt. The west-side mixer will be served from that point by another conveyor, which will cross the river on a suspension bridge.

covers the ground. It is expected that two cuts the length of the area and 40 feet deep will supply the present contract, necessitating only one relocation of the main and lateral conveyors to the 1,800-foot level.

Four sizes of gravel are required: cobbles from 3 to 6 inches; coarse gravel, 3 to 1½ inches; medium gravel, 1½ to ¾ inch; and fine gravel, ¾ to ¼ inch. Scalping and crushing of all cobbles greater than 6 inches is the first step in the process of producing the raw aggregates. Screening the 3- to 6-inch gravel, separating the smaller sizes, and washing the various grades is done in a 5-story, duplicate-unit plant. Sand is graded by the wet process in a separate plant. Three classifications are called for, and these are subsequently proportioned and mixed—the excess of any size being dumped on to the waste pile. Water necessary for classification is reclaimed, clarified, and used again. Make-up water is pumped from the river, a lift of 670 feet, and represents about 15 per cent of the required 20,000 gpm.

Material from the aggregate plant stock piles is transported by a 48-inch belt conveyor at a rate of 1,200 tons per hour to the main storage bins near the east concrete mixing plant—a distance of 6,160 feet. An aeroplane type tripper stocks the various sizes in their proper piles as they are received, the man at the tripper selecting the size to be carried by the conveyor. Electric remote control and air-operated stock-pile gates expedite the work; and an independent signal system indicates the completion of any operation. Compressed air also serves to start the flow of gravel on to the belt, a "tickler" blast of air forced upward through the gravel as a gate opens preventing the material from hanging up.

On the basis that 1,000 tons of finished aggregate will be needed per hour, the combined storage capacity of the aggregate plant and of the main storage piles is sufficient to supply the east- and west-side mixing plants for nearly four days. The several grades will be delivered to bins over the mixing plants by a single belt conveyor, which will cross the river to the west mixing plant over a 3,500-foot suspension bridge. The latter structure has two 1,437-foot main spans with an intervening tower that is mounted on cell cluster G and rises 290 feet above the top of the cofferdam. The loading of this conveyor will be controlled by a system similar to the one just described in connection with the conveyor from the aggregate-plant storage piles.

Cement is delivered by railroad to a storage plant on high ground back of and above the west mixing plant, whence Fuller-Kinyon pneumatic unloaders transfer it with air at 50 pounds pressure to eight 5,000-barrel silos. Two additional silos of the same capacity have been provided for blending. The blended bulk cement will be transported to the east- and west-bank concrete mixers by a pneumatic conveyor using air at 100 pounds pressure per square inch. As in the case of the belt conveyor that will feed aggregate to the mixing plants, the pneumatic conveyor will make the river crossing by way of the suspension bridge, except that the material will be carried in the opposite direction. The last-mentioned pneumatic unloader, together with its 11-inch pipe line, was originally in service at Boulder Dam.

Each of the two concrete mixing plants is equipped with four 4-cubic-yard mixers, with an automatic weighing batcher beneath octagonal aggregate bins, and with automatic devices for weighing cement, water, and aggregate. According to the operating schedule, a batch will be delivered to a central hopper every 45 seconds, the actual mixing taking 2½ minutes. Four-cubic-yard buckets on flat cars will receive the concrete, and 10-ton diesel-electric locomotives will haul it over steel-trestle bridges to the dam site. There whirley and hammerhead cranes will hoist the buckets from the cars and spot them over the sections in course of construction. Under the terms of the contract, no chuting of concrete is permitted on the dam.

As is to be expected on a project of this kind, compressed air is employed in numerous ways to expedite various operations. As the mantle of loosely consolidated material is removed from abutment and foundation rock, air-operated drills are being required in increasing numbers to facilitate excavating. Thus far, hand-held drills have been used almost exclusively for this purpose. Pneumatic tools, such as drills, riveting hammers, and wrenches find applications in the fabrication of box piles and other metal assembly work and in general machine-shop operations. Pneumatic hoists perform miscellaneous services. Compressed air for the major construction and drilling activities is supplied by three Ingersoll-Rand Class PRE-2 compressors, each of 2,195 cfm. piston displacement. Two of these are on the east side of the river and one is on the west side. A cross-river pipe line provides interconnection, and all three machines discharge into the general air-distribution system which supplies all sections of the construction area.

Possibly the foregoing description of the Grand Coulee plant and activities may have given the impression that the contractor's main problem has been that of working against time. That is true only in part. Until the railroad and the permanent truck and railroad bridge below the dam site were completed, cross-river communication and the transportation of supplies and equipment proved especially vexatious at times, and not infrequently necessitated changes in the construction program, as the following will make plain.

In the beginning of this article mention was made of the fact that until 1934 no attempt had ever been made to build a pile-trestle bridge across the Columbia below the Canadian boundry. Early last fall the contractor constructed a temporary bridge of this type at a point just downstream from the cofferdam area. This 672-foot span was erected in fourteen days, and at a time when the river had a flow of 50,000 second-feet. Meanwhile, the permanent bridge had been started, the expectation being that the wooden structure would be taken down in advance of high water. However, on January 20 an ice jam lodged against it, damaging the mid-stream sections to such an extent as to prohibit its use for three days. During that period a cableway at the state highway bridge, which was also under construction, transported equipment and supplies, while a catwalk suspension bridge enabled men to go to and fro. When the ice no longer threatened, the trestle was strengthened, and, aside from a permanent "kink" in its

A FOUR-FISTED PILE DRIVER

Driving of the 13,000 tons of steel sheet piling—aggregating more than 125 miles in length—to form the 3,000-foot-long west cofferdam was a titanic task. Despite winter conditions it was completed in 90 days. Contributing greatly to this quick performance was the development of a gantry frame carrying four hammers, all of which could be operated at one time.

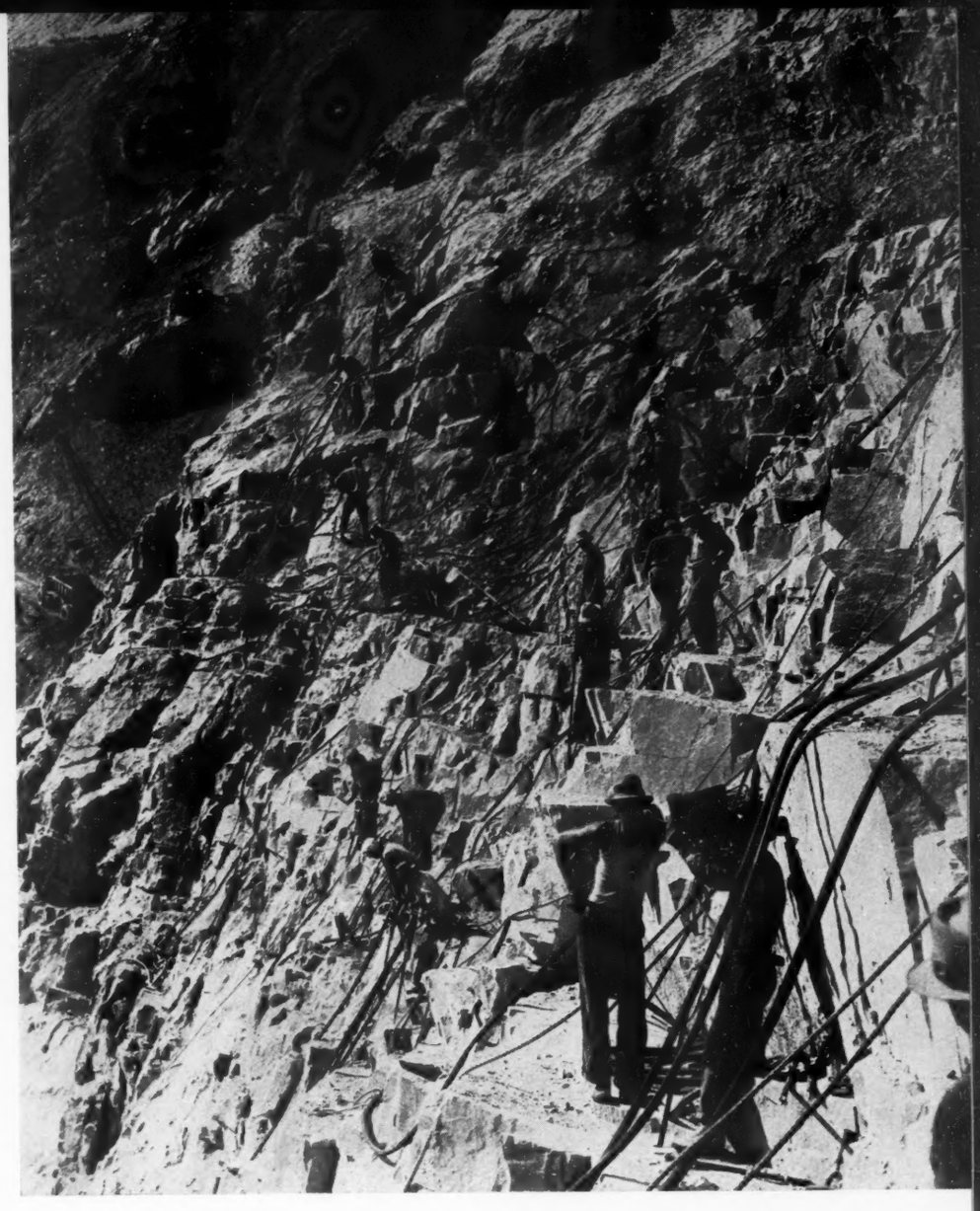
midsection, was put in good condition.

The permanent bridge was ready for traffic on March 31. It consists of four 152-foot Howe deck trusses, is 30 feet wide, and has a footwalk in addition to the railroad tracks and highway lanes. Soon after it was put in service the temporary structure was menaced by high water, whereupon it was removed by a barge derrick in a day and a half, all piling and timber being salvaged. The catwalk was then relocated farther downstream.

Independent of the Mason-Walsh-Atkinson-Kier Company, the Government had contracted for a state highway bridge between Mason City, the contractor's camp, and Engineers' Town, the Government camp. Including approaches, this steel cantilever crossing is 950 feet long and has a single 550-foot span supported by concrete piers. Several months' delay occurred in finishing this bridge because of difficulties encountered in getting the piers down to bedrock. Pneumatic caissons finally had to be used. This bridge was designed by the Washington State Highway Department and the U. S. Bureau of Reclamation, and will become the property of the state. It is on a lateral leading to the Sunset Highway Route.

The railroad spur from Odair to the dam site, which was to have hauled the 13,000 tons of steel sheet piling for the west cofferdam as well as many thousands of tons of equipment for that structure and for other purposes, was not completed until the latter part of July, 1935. The alternative was a road—and a wide, all-weather road at that. The State Highway Department therefore promptly began the rebuilding of an old county road paralleling the railroad route along the floor of the Grand Coulee to the Northern Pacific Railroad siding near Coulee City, some 32 miles away. Despite the fact that this highway was well maintained, trucking of the more bulky pieces of equipment, particularly of the 80-foot piling, was no easy task. Seven or eight of these 3,100-pound piles constituted a load for a truck and 2-wheel trailer. The swaying and unsteady loads were nursed along at speeds ranging from 3½ to 4 miles per hour the entire distance.

Possibly there is some relation between the unusual action of the spoil in Rattlesnake Canyon, which has been referred to previously, and the slides which were experienced during the initial stripping of overburden at the west abutment. In the case of some of that material, slopes as flat as 2 to 1 did not seem to be stable, and inasmuch as traffic on the railroad and highway passing through this area had to be maintained, considerable attention had to be given to its stabilization. The major slide occurred in March of 1934, when an estimated 2,000,000 cubic yards of material moved slowly down the slope of the ravine. As the rock walls of this ravine fortunately converge toward the bottom, the damage done was slight, and nothing more was involved than removing and trimming dangerous overburden.



DRILLING ON THE WEST ABUTMENT

While excavating for the foundation is going on in the cofferdam area along the edge of the river, drillers are at work on the cliffs high above cutting back into the granite to form a keyway for the concrete barrier. Although the boxlike canyon that characterizes the Boulder Dam setting is missing at Grand Coulee, nevertheless there is a vast amount of drilling and blasting to be done on the flanking rock walls.

It should be mentioned, however, that steps had been taken before that occurrence to stabilize the section by drilling six 18-inch wells, averaging 75 feet in depth, to bedrock. A 10-inch perforated casing, surrounded by gravel, was then placed in each well from surface to rock, after which 9-inch holes were drilled into the rock at the bottoms of the wells. The idea was to bring the ground water to the surface by pumping, but the slide prevented this. At that stage a 5x8-foot shaft was excavated in rock off to one side of the slide and carried down 270 feet. From there a drift was driven to connect the six wells and to drain them from the bottom. By this method many thousands of gallons of potential slide "lubricant" have been removed from this area, and today there is only a trickle from the tunnel and well system combined—in fact, less than a gallon a minute.

Present-day activities at Grand Coulee mainly have to do with concreting and associate operations. These will go forward as rapidly as seasonal and climatic conditions will permit, to the end that the entire base section of the dam will be completed in the early part of 1939. During all that period the contractor will have to control the normal flow of the Columbia River—a diversion problem of no small importance that, in itself, might be said to place the Grand Coulee Dam project among the foremost engineering undertakings of the day.

BONNEVILLE DAM

A General Description of the Dam, Power House, Navigation Lock and Salmon-Migration Structures

"I DON'T believe that you can have enough power for a long time to come. The power we are developing here is going to be power which for all time is going to be controlled by the Government."

"It has been my conception and my dream that while most of us are alive we will see sea-going vessels come up the Columbia River as far as The Dalles."

When they had heard, or read, and digested these words, the sponsors of the Bonneville Power and Navigation Project were elated. The President of the United States, speaking at Bonneville, Ore., had assured them that, aside from the economic necessity which dictated the $31,000,000 undertaking at this time, the administration's approval of the work was based on the real conviction that it would be of value to the nation.

Work on Bonneville Dam is now well underway. It is divided into four major units: a spillway dam for creating a low-water head of 67 feet; a power plant with two generators of 43,200-kw. each and with provisions for four additional units; a single-lift ship lock; and a series of ladders to enable migrating salmon to pass the obstructions. At the dam site, the Columbia River is divided by Bradford Island. The spillway section is being built across the north or main channel, and the power house and navigation lock across the south channel, the two being linked by an island crossing.

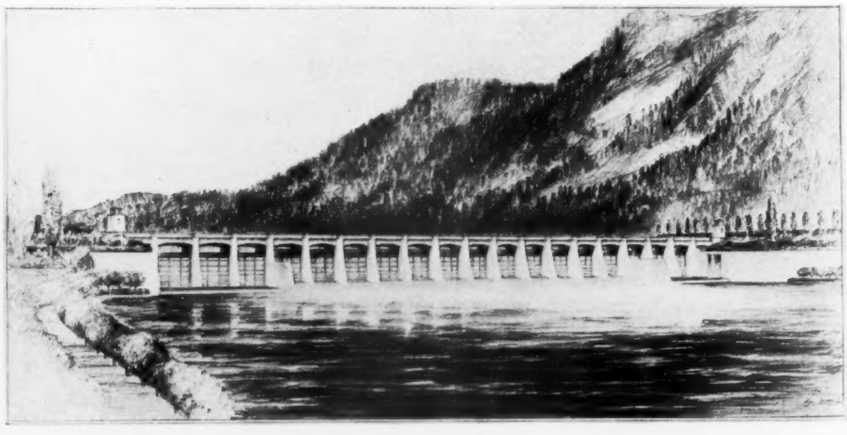
The spillway dam will be of straight-gravity, mass-concrete construction, and, when completed, will have an over-all length of 1,250 feet, a base width of 180 feet, and a height above the lowest foundation of 170 feet. Its 900-foot spillway section will be fitted with eighteen vertical-lift steel gates: twelve 50 feet high and the six others 60 feet high, but all of them 50 feet wide. Each of these gates will weigh more than 200 tons and will be divided into a lower and an upper half to facilitate erection and operation. All will be served by two gantry cranes that will travel along a concrete-encased steel truss bridge supported by the gate piers. Gate-sill elevation will be 24 feet above sea level, while the service roadway and the gantry tracks will be at elevation 97 and 99, respectively.

Ordinarily, the raising of a stream 67 feet and the consequent backing up of the flow would result in considerable encroachment upon its banks and would inundate structures near the existing waterfronts. However, conditions at Bonneville are such that, save for the four miles immediately upstream from the dam, the reservoir to be created will not raise the water line above the present maximum flood stage. In this 4-mile stretch the river now drops 35 feet forming The Cascades, at the head of which is located a barge lock. Rock ledges at the latter point dam the stream to such an extent during heavy floods that the water is raised approximately 32 feet, or to the level of what will be the shore line when the reservoir is full. These ledges are to be removed. The wider channel, together with the liberal capacity of the dam spillway gates, will make it possible to pass flood waters without materially affecting the reservoir surface. But for these fortunate circumstances the entire Bonneville project might have been greatly delayed or possibly abandoned because of difficulties incident to the acquiring of property flanking the Columbia within the reservoir area. The maximum discharge of the spillway will be 1,600,000 second-feet, sufficient to handle extraordinary floods which, according to estimates, occur at average intervals of 10,000 years. The maximum recorded flow at the dam site was 1,170,000 second-feet in June, 1894—a flood that does not recur oftener than once in 400 years.

The force of the water discharging over the spillway will be broken by a series of baffle sills on the deck of the dam. All phases of the dam construction are being checked by hydraulic experiments on a scale in some cases of 1:36. One complication has been the possible range of 60 feet in tailwater elevation and the need of providing means adequate for any flow within that range. Likewise, it has been necessary to determine with models just what would be the effect of the backing up of the water upon upstream points under all flood conditions. Many improvements have been made within the 40-mile stretch upstream to The Dalles, and while these were based on existing maximum flood levels, it has been found that the water line will remain substantially the same except within the first four miles, as has already been brought out.

The dam abutments have their footings in bedrock and have been carried well into the banks on either side in the form of concrete cut-off walls. Immediately upstream and downstream of the spillway are wing walls, 230 feet long, to guide the flow of water. As the pool elevation will be nearly at the level of Bradford Island and of the Washington shore, these walls have been extended into the banks and backed with rolled-earth embankments, forming short levees connecting with higher ground on the Washington side and with the power house on Bradford Island.

Aside from the problem of providing facilities for the passage of large volumes of water, the foundations at Bonneville were a source of much concern. In order to appreciate this, an understanding of the geology of the region is necessary. According to a Government report, the Columbia, in its course to the sea in the ages gone, has cut through both the Cascade Mountains and the Coast Range. East of the Cascades it has eroded a canyon of varying width and depth in the basalt formation resulting from the great lava flows of eastern Oregon and Washington. At the Bonneville dam site, which is near the axis of the Cascades, the river has cut through nearly 6,000 feet of volcanic formation. This was accomplished by slides and shifting of the channel. It is clearly indicated that there must have been extensive subsidence subsequent to the erosion of a channel to sea level because



SPILLWAY DAM

This massive-concrete, gravity-type structure will extend from the Washington shore to Bradford Island. It will be 1,250 feet long and 170 feet high. Outflow will be controlled by eighteen vertical-lift gates, each 50 feet wide.

the bedrock in the old channel is now submerged about 200 feet. Therefore, a rock foundation probably exists only where the Columbia is now flowing in a more recent channel. At Bonneville the location of the old channel has been well established to the north of the present channel, which it crosses diagonally just below the sites of the dam and the power house. In fact the center of the old channel appears to have been as near to them as 2,000 feet.

The bedrock in the vicinity of the dam site is largely composed of tufaceous sediments of the Eagle Creek formation, grading from shale through sandstone, grits, and conglomerates into bowlder agglomerates. There are also intrusions of andesitic lava. The overburden is made up of river and landslide deposits—the former consisting of sand, gravel, and bowlders, and the latter of an impervious mass of clay, sand, gravel, and bowlders, generally broken up and reconsolidated material from the Eagle Creek formation. Most of the subsurface information was obtained by the aid of drill holes, test pits, and tunnels, though some exploratory work was done with electric geophysical apparatus.

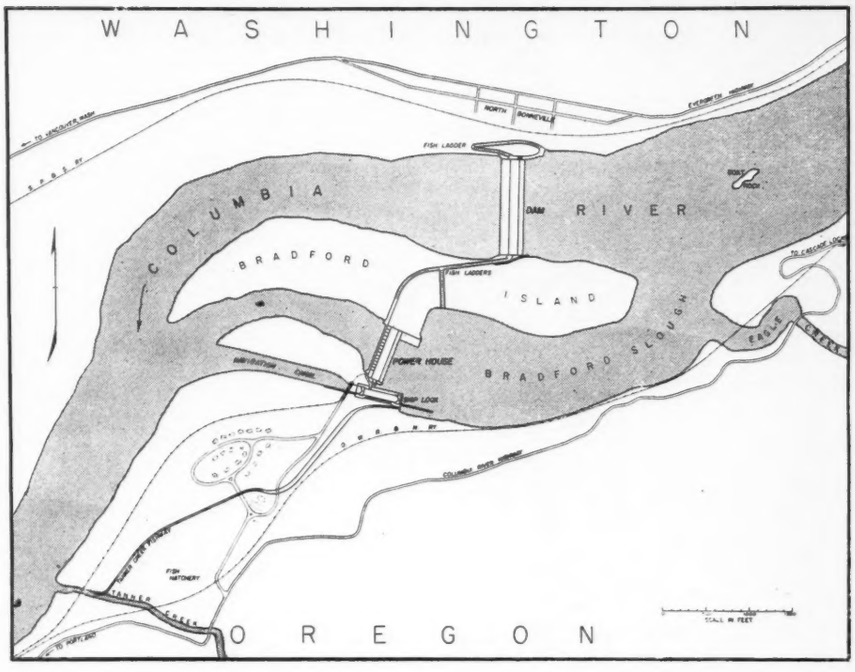
The heaviest direct load on the foundation rock will be 110 pounds per square inch, which is comparatively light; and keying the foundation rock to the mass concrete will provide a generous factor of safety in horizontal shear. Added stability will be assured by the concrete apron, 5 feet thick, that will extend 100 feet downstream from the dam.

A sill or sheet of intrusive andesite forms the foundation for both the power plant and the navigation lock in the south channel. The power plant has a base width of 207 feet and a height of 180 feet and, as now being constructed, is 608 feet long. This is on the basis of housing six 43,200-kw. generating units, although but two are now being installed. Ultimately the number may be increased to ten, which would entail additional excavating on the Oregon side of Bradford Island. To this end, a reinforced-concrete wing wall, 160 feet long and 120 feet high, has been built in the form of an inverted T in line with the last pier on that side, and this is to act as a cofferdam when the extension of the power house is being made. With that work finished at some future time, the wall may be left in the pool surrounding it because it would not obstruct the flow of water to the turbines.

Seven main piers constitute the substructure and backbone of the power house. They are on 82-foot centers, and each is 8 feet thick, 207 feet long, and 92 to 108 feet high. Headwalls in each bay reduce the gate opening to 21.33x43 feet—three openings serving each power unit. These headwalls are braced by two intermediate piers each 5 feet thick.

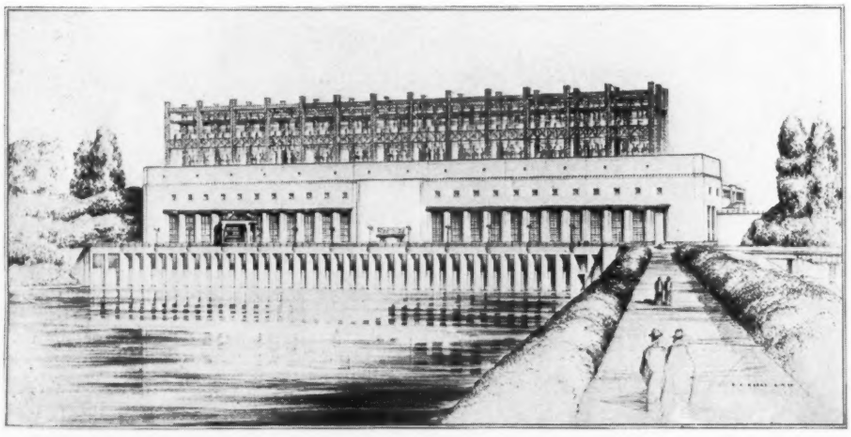
The intake openings are being closed by structural steel gates of conventional design. Two of the six gates now being installed—that is, one for each power unit—are equipped with roller bearings so that they can be raised against full head when the scroll case is empty. Thus, when the water pressure on the gates without bearings is equalized, it will be possible to move them freely. These gates will be interchangeable with the gates for the power unit serving the dam—in fact, no extra gate for this unit is being purchased at this time. All gates are being made watertight by renewable rubber strips bearing on stainless-steel wearing surfaces; but in the case of the sill there will be a metal-to-metal seal—with babbitt metal in the groove in the sill. Reinforced-concrete stop logs are being placed in the twelve intake openings of the four skeleton structures.

Conventional timber stop-log gates would be out of the question in the draft-tube openings where two 34-foot spans are formed by a 6-foot pier dividing each discharge opening. If wood were used the logs would have to be 7 feet thick to withstand the water load. As it is, "logs" of structural steel are being employed, the seal being effected with rubber in contact with bronze strips. These are designed to withstand the maximum tailrace elevation,



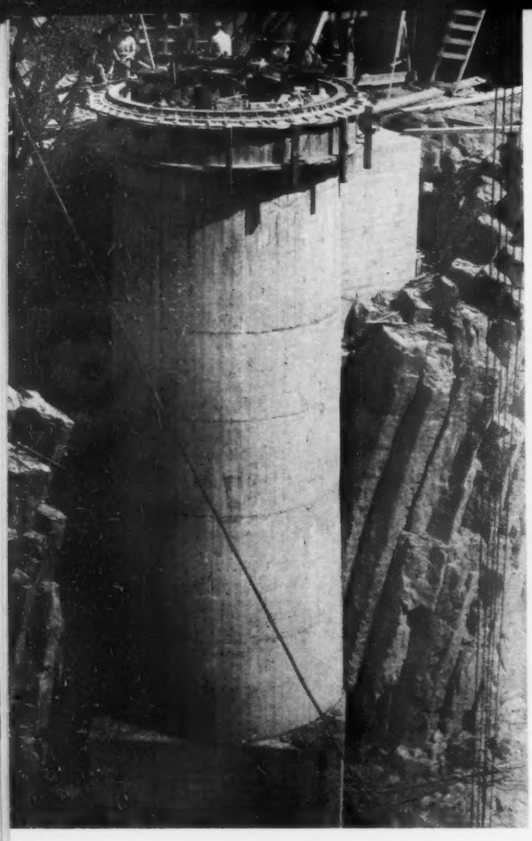
GENERAL LOCATION MAP

Bonneville Dam is a 2-part structure, the power-house and spillway sections being separated by Bradford Island. Besides these features, the undertaking includes a navigation canal and lock, as well as extensive facilities for enabling salmon to pass freely up the river.



POWER HOUSE

This structure will span Bradford Slough, adjacent to the Oregon shore. The initial power installation will consist of two 43,200-kw. generators, and provisions will be made for four additional units of the same size.



BRIDGE PIER

This massive concrete monolith will support the swing span of the bridge that will cross the navigation lock.

insuring unwatering at any time. With the flood at its maximum, the head at the bottom of the sill will be 98 feet.

All gates and stop logs will be handled by permanent cranes. A 130-ton gantry at the intake will not only serve the gates but will also be used in connection with the trash rack, with the regulating weirs of the trash sluice, and with the raking device of the trash rack. A 30-ton gantry will be installed for handling the draft-tube stop logs downstream.

The most powerful Kaplan turbines yet built will turn the generators at Bonneville. These 66,000-hp., 75-rpm. units have five automatically adjustable blades and are designed for extreme variations in head of from 20 to 70 feet. Although the power rating mentioned is for a head of 50 feet, their efficiency is but 91 per cent under this operating condition. An efficiency of 93.4 per cent is attained at higher heads when less water is available (such as a head of 60 feet—corresponding to a stream flow of 75,000 second-feet—and a water requirement of 9,650 second-feet per unit). This efficiency obtains with outputs varying from 66,000 to 35,000 hp. Thus, the Bonneville units will operate most efficiently when the water is low, and least efficiently when but half of the river flow can be passed through the power house.

Each of the two 3-phase, 60-cycle generators will have an output of 43,200 kw. at 13,800 volts at 0.9 power factor, and will have a direct-connected and a pilot exciter. Surface coolers and an enclosed ventilating system will prevent overheating. Transformer banks, one for each generator, will be located over the head-gate structure. These will step up the voltage to 110,000—current being transmitted to the Oregon and the Washington shores by overhead lines.

The power house will be one continuous room. Adjoining the generator on the Oregon side will be the control station, the 4,000-kw. turbine serving the plant, and an assembly bay. In it will be installed two 300-ton cranes each with a clear span of 70 feet and using a 30-ton auxiliary. Equalizer beams will assist in lifting the heaviest load, the 400-ton generator rotor. Transformer stations and control rooms for the electric equipment of the spillway dam and for certain of the fishway structures will be in the abutments of that dam.

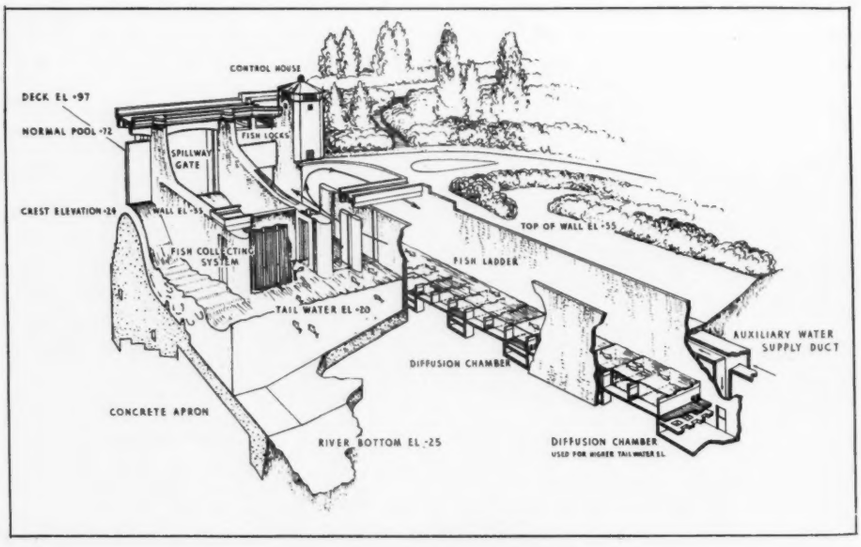
The intrusive andesite sill extending across Bradford Slough dictated the design of the navigation lock at that point. Normally, with a maximum low-water lift of 67 feet a double-lift or tandem lock would be used. Locks of this type, however, are comparatively long; and it was determined upon exploration of the site that the foundation would permit the building of only a single-lift lock 500 feet long. Although originally planned to be a barge lock with a 26-foot depth of water over the lower sill 35 per cent of the time, a change order was issued by the Secretary of War on August 14, 1934, with the result that the lock, as now being built, will have 26 feet of water over the sill 98 per cent of the time. It has a 76x500-foot chamber which will be filled through an intake at the upstream end of the north wall. Two 7x11.5-foot Taintor gates at this point control the water, which will be led through a 14-foot longitudinal culvert beneath the floor of the lock and branching off to 41 floor ports. These same ports will serve to empty the lock, a duplicate set of Taintor gates regulating the discharge to five 6x7-foot floor ports downstream from the lower miter gate.

The backbone of the miter gates are 44-foot horizontal girders framed with girders and intercostals and faced with plain and buckle plates. The upper gate is 45 feet high, while the larger lower one—each half of which weighs 525 tons—is 102 feet high and has air chambers to reduce its bearing load while in service.

Provision has been made for closing the lock should the upper miter gate become damaged. It is in the form of an emergency dam consisting of a nickel-steel horizontal bulkhead operating in grooves in the walls just upstream from the upper sill. This bulkhead is made up of ten 3.9x80-foot sections which will be lowered by the aid of a spreader from a post derrick on the south wall and will effect closure at any pool elevation. There is a similar bulkhead below the lower miter gate for dewatering the lock in case of emergency.

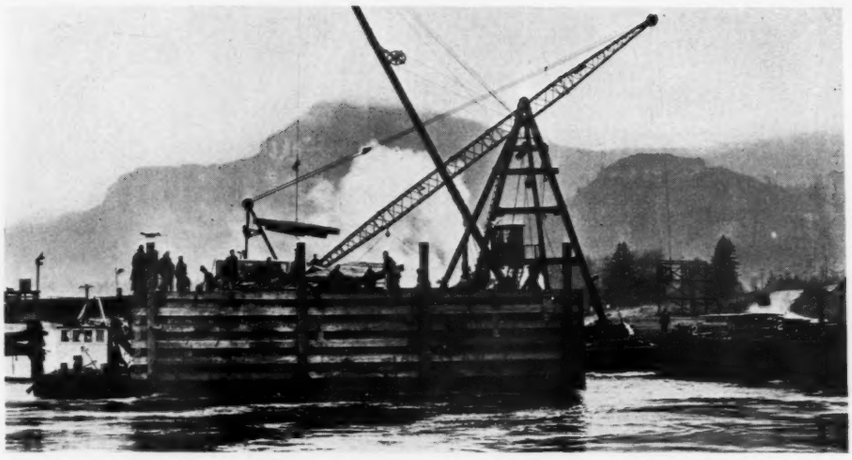
Vessels will pass in and out of the lock under their own power and will be held in position during raising or lowering by floating mooring bits—three along each side wall. The time for either filling or emptying has been estimated at fifteen minutes. During periods of low water the lift will be 67 feet; at normal flow, 59 feet; and at extreme high water, such as the 1894 flood—it will be 30 feet. All machinery will be electrically driven and controlled from stations at either end of the north wall of the lock.

Commercial interests along the Columbia River have been much concerned about the effect of the dam on fish, especially on the migration of the salmon to and from the Pacific. Since the days of the fish-



ONE OF THE FISHWAYS

A sectionalized diagram of the facilities being installed at the south end of the spillway dam. The ladder consists of successive pools of flowing water arranged like a flight of stairs. Instinct causes the fish to climb the graduated waterfall. Those that do not make the ascent voluntarily are to be directed into hydraulic lifts which will elevate them to the reservoir level and discharge them.



PLACING CRIB FOR SPILLWAY COFFERDAM

Preparatory to building the offshore wall of the cofferdam, a relief map of the river bottom along that line was made. Models of the cribs were then constructed, their bottoms shaped to fit the irregular surface. These served as guides in forming the full-sized cribs.

eating Indian tribes, the Columbia has been a source of food and revenue to the Northwest. At present the yearly income of the salmon industries along its banks averages $10,000,000, while that of the numerous ocean fishing fleets, which depend largely for their catch upon Columbia River salmon, is estimated to be equal if not greater. The Government is bound by treaty rights with certain Indians to insure the migration of fish past Bonneville Dam; and it is worth noting that some of their religious rites are based upon the annual return of the salmon to their spawning grounds. Even the closed seasons—March 1 to May 1 and August 25 to September 10—do not affect those tribes.

Salmon normally make the trip from their hatching grounds to the sea and back but once. After a two to seven years' stay the fish return to their home river, usually during the low-water period, and start the long journey upstream. On their way to the grounds they are very sportive and seem to revel in encounters with falling water, despite the fact that they are not known to feed. After they have spawned they generally die. On their trip seaward, the young keep close to the shore, and as they can safely ride over the spillway crest, or even through the power house and out of the draft tubes, that phase of the problem presents no difficulties.

Attracting the mature salmon to ladders and elevators, away from the spillway and draft tubes, is another matter. However, they seem instinctively to avoid the center or the swifter current of the broad stream, and with this in mind, three sets of ladders, with their entrances downstream, are being provided on the Washington, Bradford Island, and Oregon shores, in the latter case below the approach channel to the lock. They will have a width of 30 or 40 feet and will be divided into 16-foot pools with a 1-foot drop between pools. A maximum of 2,800 cubic feet of water will be diverted over them every second.

Fish that do not reach these ladders and attempt to swim against the spillway overflow or the discharge from the draft tubes will eventually find falling water that will not impede their progress at the ends of these structures. At these points they are to be collected and led into hydraulic lifts. At intervals the entrance gates to these lifts will be closed; the water raised to pool elevation; and the fish forced out to continue their journey. The combined capacity of these systems is estimated at 100,000 fish per day during the peak of migration.

Of the three huge "New Deal" dams—Bonneville, Grand Coulee, and Fort Peck—the first alone was favored with ample transportation facilities. Barge traffic from Portland, the nearest harbor for seagoing vessels, passes the dam site, while two railroads and two highways, one of each on either side, parallel the river. Airways follow its course in traveling to and from Portland, about 42 miles downstream and almost due west of Bonneville. While the planes make no stop at the latter place, they do land at Portland, where are located the offices of the army and civilian engineers in charge of the design and construction of the dam and which is the goal of numerous businessmen flying to the project from the East.

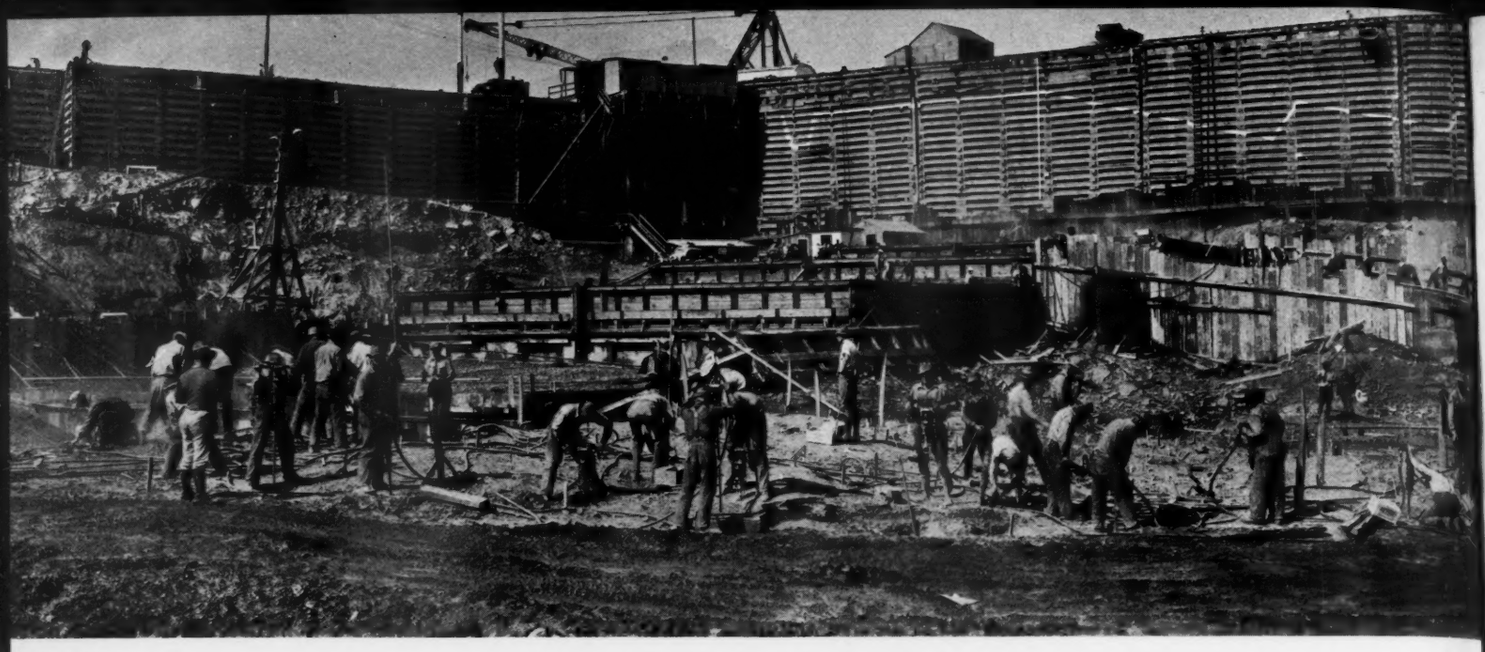
Aside from the work in connection with the dam itself, sections of the Columbia River Highway and of the Oregon-Washington Railroad & Navigation Company necessitate relocating. The Spokane, Portland & Seattle Railroad, on the Washington side of the river, was above the 1894-flood elevation, and therefore involved nothing more than changing submerged drainage outlets to meet the new conditions, placing riprap on exposed banks, and giving the track immediately opposite the dam a rise of 7 feet.

On the Oregon side of the river the roadbed is at a much lower level and therefore calls for extensive relocating. Opposite the dam, the track elevation is being raised 35 feet. To get this grade, work has to be begun 1.5 miles downstream and carried for a distance of 2.5 miles upstream along the reservoir to a point where it connects with the old line. Within the latter stretch the tracks traverse Ruckel Slide—an unstable and troublesome area—for 1½ miles. The difficulties of maintaining a roadbed there are well known to the railroad concerned. After heavy rains, for example, which seep through to the porous formation back of the slide, it is no uncommon thing to find that the roadbed has been moved several feet nearer the river. Efforts to stabilize the section are at present confined to draining the water from the porous fill by means of tunnels. Riprap has been placed at the toe of the slide to protect the bank from the action of the pool that will be formed there.

Bonneville Dam, because of its nearness to a number of towns and cities—particularly Portland, did not present much of a housing problem. Each contractor has made provisions for his own workers, and the present camp and shopping center of the Columbia Construction Company is a model of comfort and convenience. One section of it has been reared for permanence, and in it are twenty homes for the Government resident supervisors and inspectors, a civic auditorium, the administration offices, and a school, all of colonial architecture, attractively laid out, and landscaped. Upon the completion of the project, this section will become the base for the operating personnel of the Bonneville Dam.

RELOCATING RAILROAD

Railroad-relocation work on the Oregon shore is complicated by slide conditions that necessitate precautionary measures.



RECENT VIEW IN SPILLWAY-DAM AREA

In the foreground workmen with S-49 "Jackhamers" are taking up bottom rock. Beyond them are blocks of concrete already poured and still encased in their forms. The white line on the crib wall shows the contours to which the foundation floor is being finished before the pouring of concrete. Note how this will key the dam to its supporting rock.

Constructing Bonneville Dam

AS ORIGINALLY laid out, Bonneville Dam was to cross the main channel of the Columbia at a point not far upstream from the present site where the river is narrow and where Boat Rock is situated. It was contemplated to construct a gravity gate-controlled overflow section, arched in plan and 750 feet long, between the Washington shore and Boat Rock; a similar gate-controlled spillway on Boat Rock; and a nonoverflow slab-and-buttress hollow dam connecting Boat Rock with the head of Bradford Island. During preliminary explorations made in 1930 and 1933, the only foundation rock found in the vicinity of Bonneville was at Boat Rock. Accordingly, a contract was awarded on November 3, 1933, for enlarging the diversion channel and excavating the foundations for the nonoverflow dam. This work was stopped by a severe winter flood on December 25 following.

In the meantime additional exploratory drilling at the power-house and lock site revealed an andesitic sill extending in a northeastly direction across Bradford Slough and under Bradford Island. Further drilling in the main channel along the prolongation of this sill was at once undertaken to determine whether it extended to or across the main channel. No igneous rock was discovered there, but drilling proved the existence of a considerable area of Eagle Creek formation—a broad and gently rounded ridge continuing under the main channel at both banks and lying at much higher elevations than the Boat Rock foundation.

Designs and comparative cost estimates for a dam at the lower site were made and showed: first, a large saving in construction cost; second, more favorable hydraulic characteristics for the spillway; third, fewer hazards in cofferdamming, construction, and in diverting the river because of more room and bedrock nearer the surface. Plans were accordingly revised, and on February 15, 1934, a contract for the power-house and lock excavations was awarded to the Guy F. Atkinson Company. This contract was for the sum of $1,173,390, and called for the removal of about 850,000 cubic yards of overburden and rock by September 25. At the Government's expense two earth dikes were built across Bradford Slough. These required 95,000 cubic yards of common excavation and 55,000 cubic yards of impervious fill, all from convenient shore locations. About 25 acres were enclosed within these cofferdams, which were designed to permit uninterrupted spoil removal from the area during the high-water period in summer.

With heavy spring rains swelling the Columbia to unseasonal levels in March, it seemed likely that the cofferdams in the slough would be lost, for at one point during the piling on of fill in the battle with the river the tops of the cofferdams were just 6 inches above water. On Easter morning, however, the river level began to drop, and preparations were immediately made for unwatering the site. Pumping began on May 12, and was paid for by the Government on a basis of acre-feet per foot of lift. Later, with the river continuing at flood stage, infiltration was at the rate of 50,000 gpm.; and most of the time excavating was in progress the pool was held at elevation −48, with infiltration averaging 30,000 gpm.

The power-house and lock foundations involved the removal of 1,305,000 cubic yards of material consisting of 488,000 cubic yards of common excavation and 817,000 cubic yards of intermediate and solid rock. The latter, with the exception of 300,000 cubic yards which later served as riprap at Ruckel Slide, was wasted on the Bradford Island levee which will connect the power house and the spillway dam. During the course of the Atkinson contract, the pumping out of the cofferdam area was equivalent to lifting 1,247,000 acre-feet of water one foot.

Meanwhile, the contract for the excavation and construction of the spillway dam was awarded to the Columbia Construction Company, an affiliate of five of the companies constituting Six Companies Inc., builders of Boulder Dam. Preliminary work on this $8,972,650 part of the program was started on July 17, and en tailed clearing the site and creating a permanent 542-man camp. During the first low-water season of 1934-35, it was planned to do such necessary shore excavating as could be accomplished and to

rear the midstream partition of the 2-stage cofferdam. This structure consisted of timber cribs from 36 to 60 feet wide and varying in length from 60 feet for the regular rectangular cribs to 112 feet for the V-shaped end sections.

An accurate contour map of the channel was used to make a miniature relief map, and models of cribs served as guides in building the full-sized cribs. Each of these was designed to fit in a definite place—the bottom of the crib conforming to the contours of the river bed at that place. They were erected to a height of 12 feet on a 100-foot launching way and floated to their respective positions after an additional 12 feet had been added while at anchor alongside a 300-foot timber-pile trestle extending out from the shore. Then they were filled with gravel overburden and dredged material. When properly located, the cribs were heightened as required, and ranged from 40 feet near shore to 61 feet in midstream. Steel sheet piling was driven along the outer face of the cofferdam cribs, the average penetration in the Eagle Creek formation being 2 feet. An impervious fill was placed along the shore legs, and in the case of the midstream section, where the swift current prohibited the use of toe-fill material, clay inside the wall of piling served as an effective seal.

GENERAL VIEW AT BONNEVILLE

This picture was taken during the high-water period of last May. It shows the power-house section, at the left, well along towards construction in a basin in Bradford Slough between protecting cofferdams. At the right is the cofferdam for the construction of the south half of the spillway section in the main channel of the river. During this period of heavy flow the cofferdam area was flooded and work within it had to be halted temporarily.

Although the contractor had originally planned to construct only the midstream section of this cofferdam during the 1934-35 low-water season, he was able, on the strength of an agreement reached with the U. S. Engineer Office, to finish the side walls connecting it with the Bradford Island shore, thus shortening the building period by several months. With the cofferdam finished and unwatered, 330,000 cubic yards of material was removed within a month's time. It was excavated with draglines and shovels and hauled by trucks and tractor-wagons to the Bradford Island levee. On April 19, when rising water caused excessive infiltration, the area was cleared of all equipment, and on May 8 the cofferdam was inundated. During maximum high water the river level was about 12 feet above the top of the structure. Excavating on shore, however, was continued, most of the equipment being concentrated on the fishways and on the approach channel for the navigation lock.

As soon as the flood began to recede during July and August—the Columbia dropping at an unusually rapid rate—the contractor started to unwater the 410-acre-foot pool with his pumping plant, which had a capacity of 180 cubic feet per second. When the water level had fallen to elevation –8, excessive leakage was observed around the cribs in the corner of the cofferdam where the midstream and the upstream sections joined, making it advisable to allow the pool to refill and to drive additional piling at the point of seepage. Aside from this more or less expected leak, no further trouble was experienced with this barrier which half blocks the main channel of the river. When it is considered that the flow during extreme high water was at the rate of approximately 15 mph., it is remarkable that the cofferdam remained in its true position. The southern half of the concrete base of the spillway dam is now being poured in this area up to elevation –8.

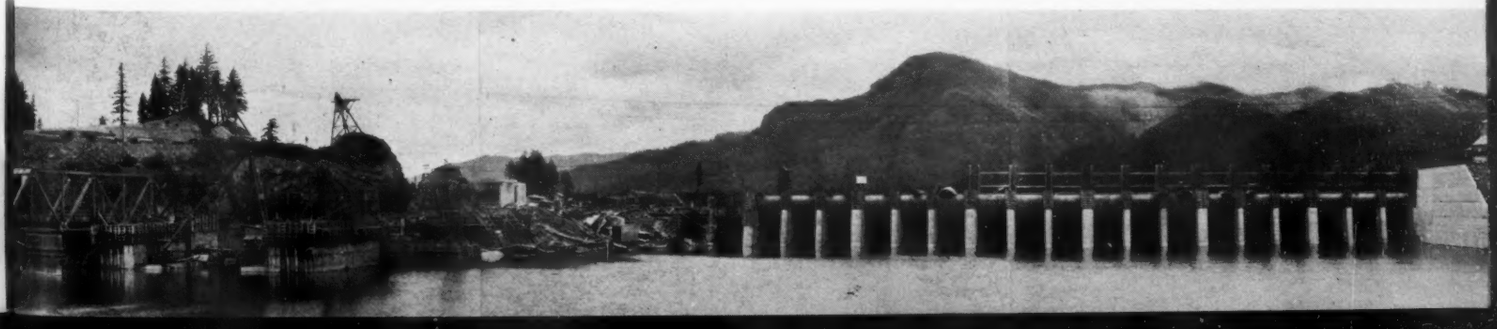
On July 31, 1934, shortly after the Columbia Construction Company had begun work on the spillway dam, the contract for the power house and lock was awarded to the General Construction Company and the J. F. Shea Company. The contract amounted to $3,895,592, but was increased by $1,200,000 when the Government authorized the building of a sea lock instead of the barge lock originally specified. As a result of this change, the depth of the lock was increased by 11 feet and the length from 360 to 500 feet. The latter companies installed their own pumping plant for unwatering the power-house cofferdam. It was of the closed type so as to prevent winter freeze-ups. The plant previously used there by the Guy F. Atkinson Company was of the open-flume type.

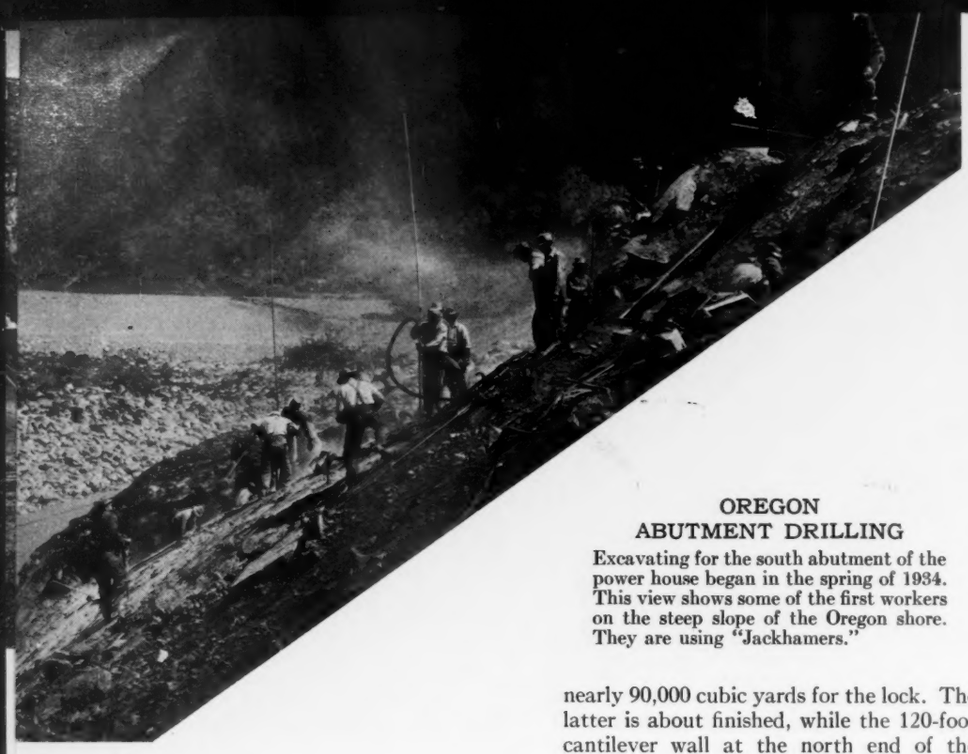
Concrete aggregate for the power house and lock is being supplied by a plant situated in the heart of Portland. Raw material is obtained from the Willamette River about two miles above the city and transported by barges to the plant, which has a capacity of sixty 40-ton cars in 24 hours. Washed and graded sand and gravel are shipped from there by rail to Bonneville, where stock piles, together with aggregate-handling facilities, are conveniently located on Bradford Island adjacent to the power-house site. The arriving material is dumped into the hopper of a bucket-and-belt conveyor feeding the stock piles, whence a belt conveyor carries the aggregates to the batching plant.

Cement is stored in a steel silo which has a capacity of fifteen cars and is about 250 feet away from the mixing plant. A cable drag scraper unloads the bulk material from the cars directly into the hopper of a pneumatic conveyor which is arranged to

POWER DAM AND LOCK

A view taken last June, showing the upstream face of the power-house dam and, at the left, the lock site with one concrete monolith in place. Construction of the power-house superstructure will be carried on during the coming winter.





OREGON ABUTMENT DRILLING

Excavating for the south abutment of the power house began in the spring of 1934. This view shows some of the first workers on the steep slope of the Oregon shore. They are using "Jackhamers."

discharge either into the silo or into bins at the combined mixing and batching plant. The latter automatically maintains a batching schedule of 25 seconds, and has a capacity of more than 2,000 cubic yards of concrete daily. A swivel chute feeds the 3-cubic-yard mixers which, in turn, discharge into 6-cubic-yard cars. These haul the concrete over standard-gauge track to a loading dock under a cableway having a capacity of 15 tons. Each car empties its load into a 6-cubic-yard bottom-dump bucket which is picked up and conveyed by the cableway to the form being poured in the power-house or lock area.

From the 145-foot head tower on Bradford Island to the two 75-foot movable tail towers on the Oregon shore, the cableway has a span of 1,390 feet. The tail towers travel on a 40-foot-gauge, 600-foot radial runway; and to counteract the horizontal pull exerted on them by the cables, each tower is provided at track elevation with a horizontally disposed wheel that bears against a rail placed with its web in a horizontal plane. In the case of certain sections that cannot be reached by this cableway, the concrete is transported by trucks and placed pneumatically.

The plant just described has been in use since November 1, 1934, and has handled in excess of 120,000 cubic yards of concrete for the power-house substructure and nearly 90,000 cubic yards for the lock. The latter is about finished, while the 120-foot cantilever wall at the north end of the power house and the fishway in front of it are finished—the contract for the substructure being scheduled for completion in December of this year. Bids for the construction of the superstructure were opened on October 8.

Because the spillway dam will require far greater quantities of material, and also because of its design and location, the Columbia Construction Company has provided a considerably larger concrete plant for this part of the project. It is located just below the dam site on the Washington shore, and has a capacity of 4,000 cubic yards per day. Pit-run sand and gravel from the Rabbitt Island and Bingen deposits, 50 and 25 miles upstream, respectively, are brought by gondola cars to the aggregate plant. Crushing of oversize rock is done at the pit and under track hoppers, whence all material is delivered by belt conveyors to the screens and classifiers. Storage piles, having a combined capacity of 2,000 cubic yards, receive all the classified material by way of a 107-foot, 24-inch horizontal conveyor having a tripper arrangement at the stock-pile end. Provision has been made for recrushing the larger sizes to make available a larger proportion of smaller aggregates, should that become necessary. From the stock piles a belt conveyor, 368 feet long and on a slope of 18.25°, carries the material to four storage bins at the mixing plant. These bins are octagonal in form, 30 feet in diameter and 57 feet high, and have a capacity of 1,500 cubic yards each. They are of timber-crib construction and lined with tongue-and-groove lumber.

Cement, delivered in bulk in box cars, is unloaded by a cable-controlled drag scraper directly into the hopper of a screw conveyor extending to the base of three storage silos. There a bucket elevator carries the cement to the top, where another screw conveyor discharges it into any one of the silos. Screw conveyors also transfer the cement from the silos to the batchers, one conveyor serving each batcher.

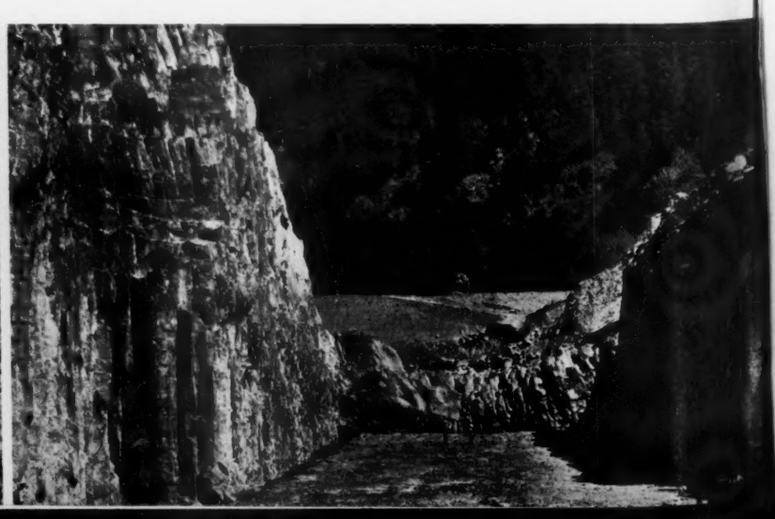
The mixing plant is 380 feet upstream from the aggregate plant and is equipped with two automatic batching units—previously used on the San Francisco-Oakland Bay Bridge—and with four 4-cubic yard mixers from Boulder Dam. A swivel chute receives the batched material from Kron dial scales and weighing hoppers and feeds it into either one of two mixers. These, in turn, discharge directly into 8-cubic-yard bottom-dump buckets on flat cars that haul the concrete to a loading platform under a cableway spanning the spillway-dam site.

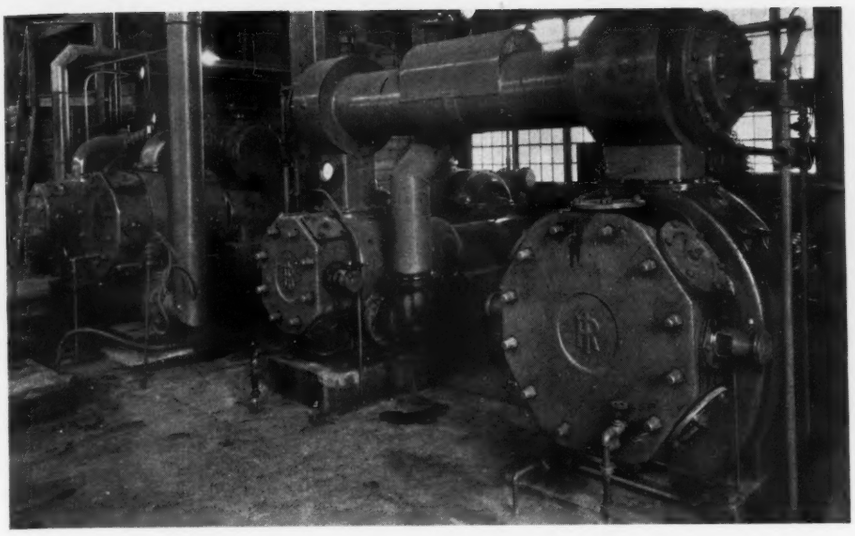
The cableway has a capacity of 20 tons, and from its two 90-foot movable head towers on Bradford Island to the stationary 223-foot tail tower on the Washington shore has a length of 2,022 feet. The latter is said to be the highest of its kind ever constructed. Boulder Dam contributed the head towers, which run on a 45-foot-8-inch-gauge, 892-foot radial track. In their case, the horizontal pull of the cables is overcome in much the same manner as already described in connection with the tail towers of the Bradford Slough cableway. The head towers are at elevation 203, and the tail tower at elevation 285. A 6 per cent cable sag assures a minimum clearance of 22 feet at the highest point in the spillway dam.

In June, 1934, the P. L. Crookes Company began relocating the tracks of the Spokane, Portland & Seattle Railroad along the Washington shore under its $339,335

EXCAVATING FOR SHIP LOCK

As the views below show, the ship lock was literally hewn in solid rock. The left-hand picture shows drillers preparing holes for shooting off one of the series of 14-foot vertical lifts by which the rock was taken out. On the right is the finished excavation.





ONE OF THE COMPRESSOR PLANTS

Both stationary and portable compressors are in service at Bonneville. This is the central plant of the Columbia Construction Company. On the right is a Class PRE-2 direct-connected, synchronous-motor-driven unit of 2,195 cfm. piston displacement. The other machine is a belt-driven Type XCB-2 of 1,052 cfm. piston displacement.

contract. This work, which is now completed, involved about 400,000 cubic yards of excavating. One major item was the erection of new piers for the Hamilton Creek Bridge that crosses the line, and the transfer of its 150-foot through-truss span to those piers about 27 feet upstream. This was done without interrupting traffic, a temporary pile-trestle-and-steel-girder bridge serving the road.

The work of relocating the Oregon-Washington Railroad & Navigation Company tracks presented more of a problem and was awarded to two contractors. The first contract, now completed, was let to the Orino-Bell-Malcom Company for $846,247, and covered 1½ miles of grading from Moffett Creek to Tanner Creek, entailing about 400,000 cubic yards of excavating; driving Tooth Rock Tunnel; building piers and abutments for Eagle Creek Bridge; constructing Tanner Creek Viaduct; and placing about 300,000 cubic yards of riprap at the toe of Ruckel Slide.

Tooth Rock Tunnel is 600 feet long, 31x36 feet in cross section, and lined with concrete. It was advanced from the upstream portal only, and excavated full face by the aid of a truck-mounted jumbo drill carriage that made it possible to pull about 10 feet per round. Shoring was necessary only in one short stretch encountered at the start. Three steel forms, each 18 feet long, were used in lining the side walls and the arch. They were mounted on wheels and, as the work progressed, were moved along on tracks laid on the concrete floor. After a form had been set up and the open end plugged, the joints were sealed to prevent concrete leakage—the mixture used for the purpose being applied pneumatically with a spray nozzle. Stripping was done in from 36 to 48 hours after pouring. Tanner Creek Viaduct is 899 feet long and supported by sixteen earth-filled spandrel arches. About 11,000 cubic yards of concrete have gone into this structure, which rises to a height of 50 feet above the stream bed and has a 3° curve for double tracks.

The contract covering the remainder of the railroad-relocation work on the Oregon shore was awarded to Sam Orino. It amounts to $793,191 and includes: excavating 530,000 cubic yards of solid rock and 280,000 cubic yards of unclassified material; placing 180,000 cubic yards of additional riprap at Ruckel Slide; erecting a steel-and-timber-deck, through-truss bridge across Eagle Creek; removing two old bridges; and taking up 27,000 feet of track and laying 34,000 feet of track along the new route. These operations are taking place within a stretch of four miles between Moffett Creek and Cascade Locks. Most of the rock has been excavated in a single cut east of Eagle Creek. As this cut is directly under the Columbia River Highway, it is necessary to run both the railroad and the highway through it at different elevations.

Throughout the entire course of this huge power and navigation project, the Government is playing a very important part. Aside from furnishing all plans and designs, supervising and directing the work, supplying all materials and equipment used directly in and for the building of the various structures, the Government is responsible for the cofferdams and for any damage that may result through the failure of any one of them. The cost of their unwatering is defrayed by the Government; and they are constructed under its supervision and inspection at unit bid prices. In fact, the cofferdams are the property of the Government.

Furthermore, 36-inch holes are being drilled in the bedrock—in some cases as much as 60 feet deep—by Type WS "Calyx" drills to permit geologists to make visual examinations of underlying strata of foundation rock. Pervious gravels beneath impervious landslide material on the Washington shore have been investigated by means of a 7x8-foot test pit on the axis of the dam. This pit was carried down in three stages: through the impervious landslide by ordinary timbering methods; through the pervious gravels to bedrock, at elevation −45, by the use of a pneumatic caisson; and from that point on, after sealing off with concrete, the remaining 28 feet were driven to elevation −73 by the open-shaft method. Drainage tunnels have been carried into Ruckel Slide with Government equipment by hired labor; and springs with a flow exceeding 900 gpm. have been tapped in the talus at the base of the slide-covered basalt cliff. The expectations are that by thus draining the water from this area it will become stabilized.

SOUTH COFFERDAM FOR SPILLWAY

Good fortune and fast work enabled the contractor to construct the timber-crib cofferdam for the south half of the spillway dam ahead of schedule. This picture, taken in February, 1935, shows the structure in place and excavating underway. In May the cofferdam was inundated by floods and was not dewatered until midsummer.

CONSTRUCTION PROGRESS

IT HAS been said that there is virtually no construction task that engineers could not accomplish. It is conceded, for example, that there are no considerable physical or technical problems that would prevent the erection of a skyscraper having twice the height of the Empire State Building. There are economic limitations, of course, and these, in the long run, are the factors that control the size of structures.

When one examines the Grand Coulee and Bonneville dam undertakings in some detail, as we have done in this issue, one receives a rather awesome impression of the versatility, ingenuity, and complete assurance with which the engineers and builders have approached their huge and difficult labors. The very conception of the Grand Coulee project is daring. The idea of lifting enormous volumes of river water more than 600 feet to transform more than 1,000,000 acres of semidesert land into highly productive farms, something entirely feasible now, would have brought ridicule upon anyone bold enough to propose it only a few decades ago. Even in this enlightened technical age, the scheme embraces performances which appeal to the imagination. Who, for instance, can visualize a pump driven by a 33,000-hp. motor and having a discharge opening 8½ feet across? Yet the specifications call for twenty of them, each one capable of lifting 3,600,000 gpm. to a height of 370 feet. Working but one-fifth of the time, just one of them could handle New York City's entire municipal water supply. No such pumps have ever been built, but the designers of the Grand Coulee project did not hesitate to incorporate them in the plans, for they had faith in the capacity of American manufacturers to turn them out.

Again, consider the generating units that are to be installed at Grand Coulee Dam. Ultimately there will be eighteen of them, each rated at more than 140,000 hp. They will be more than one-fourth greater in capacity than the present largest water-turbine generators now being placed at Boulder Dam. Just as remarkable is the plan to step up the voltage to 220,000 to transmit the power long distances. It was not long ago that transmission of electricity at 100,000 volts was considered an achievement of a high order.

In the performance of its construction contract, the Mason-Walsh-Atkinson-Kier Company is exercising resourcefulness and boldness which match those of the designers. Given the task of erecting a cofferdam of unprecedented size in a limited period before high water set in, mechanical shortcuts were devised by means of which the allotted time was more than halved. The peak of achievement is reached, however, in the conveyor systems, one for moving muck out of the excavation area and another for bringing in concrete aggregates. There are no lines of straining trucks toiling their way up stiff grades with heavy loads and then rumbling back down with all permissible speed to take up another burden. Instead, great snaky structures, motionless in themselves but with traveling belts in their "innards," relentlessly and monotonously transport almost unbelieveable quanties of materials with no confusion or scurrying about the landscape.

The idea of using belt conveyors sprang from their successful application by the Silas Mason Company during the driving of the East-Boston Vehicular Tunnel several years ago. The contractor there gambled a considerable sum on his conviction that a conveyor would effectively transport muck and thereby reduce the congestion which has always attended tunneling jobs. It is doubtful, owing to the comparatively small size of the contract, whether the initial investment paid out, but there can be no question that it paved the way for rich returns on the Grand Coulee job.

When one adds the advances in construction technic registered at Boulder Dam to those now being displayed in the Northwest, the progress that has been made in five years looms up as truly amazing. Each succeeding big undertaking brings with it startling departures that set new standards for speed and economy of performance.

SAFEGUARDING EARTH DAMS

SAFETY valves for pressure vessels are commonplace, but the idea of incorporating something to serve a similar purpose in dams is new and novel. Engineers try to design such structures so that they will unquestionably be strong enough to resist peak pressures to which they may occasionally be subjected, and as a rule they can do no more. However, in the case of a dam that was constructed in 1931 as a unit in the water-supply system of Hornell, N. Y., conditions were such that a unique safeguard could be included, and this was done.

The method followed was a simple one, consisting merely of purposely building a weak section at one end of the dam. The theory was that, in the event of inordinate inflow which might endanger the entire dam, this weak link would wash out and relieve the pressure on the remainder of the structure. The dam is of the earth-fill type, with a reinforced-concrete core wall. The core wall was omitted from the safety-valve section, which is located between the spillway and the shore and consists of an embankment resting on the sloping side of the natural valley surface.

The dam is 425 feet long at the top and 75 feet high. The spillway is designed to carry an 11-foot crest before the core wall is overtopped, but the safety plug is of such a height that water will flow over it after the depth of water in the spillway passes 8 feet.

Thus far there has been no opportunity to test the effectiveness of the safety feature. During the flood period of last July the greatest depth of water in the spillway was 4¼ feet, or 3¾ feet short of the depth required to bring about overflow of the coreless section.